WEST HACKBERRY TERTIARY PROJECT

Annual Report for the Period
September 3, 1994 to September 2, 1995

By
Travis Gillham
Bruce Cerveny
Ed Turek

May 1996

Amoco Production Company
Houston, Texas

Bartlesville Project Office
U. S. DEPARTMENT OF ENERGY
Bartlesville, Oklahoma
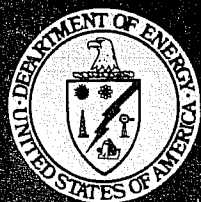
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Annual Technical Progress Report (9/3/94-9/2/95)
West Hackberry Tertiary Project

1.0 ABSTRACT

1.1 Brief Description of Research

The West Hackberry Tertiary Project is a field test of the idea that air injection can be combined with the Double Displacement Process to produce a low cost tertiary recovery process which is economic at current oil prices. The Double Displacement Process is the gas displacement of a water invaded oil column for the purpose of recovering tertiary oil by gravity drainage. The Double Displacement Process is based upon the concept that in fields such as West Hackberry waterdrive recoveries are typically 50%-60% of the original oil in place while gravity drainage recoveries average 80%-90% of the original oil in place. Therefore, by injecting a gas into a watered out reservoir, a gas cap will form and additional oil can be recovered due to gravity drainage. Although the Double Displacement Process has been shown to be successful in recovering tertiary oil in other fields, this project will be the first to utilize air injection in the Double Displacement Process. The use of air injection in this process combines the benefits of air's low cost and universal accessibility with the potential for accelerated oil recovery due to the combustion process. If successful, this project will demonstrate that the use of air injection in the Double Displacement Process will result in an economically viable tertiary process in reservoirs where tertiary oil recovery is presently uneconomical.

1.2 Summary of Key Results and Conclusions

After the first ten months of air injection, evidence of spontaneous in-situ combustion, pressure response, early nitrogen breakthrough and possible production response has been obtained. In addition, all project performance obtained to date confirms the original geologic picture.

2.0 EXECUTIVE SUMMARY

2.1 Background

September 3rd, 1995, is the two year anniversary of the start of the West Hackberry Tertiary Project. The following report is the Annual Technical Progress Report for the second year of the West Hackberry Tertiary Project and covers the time period from September 3, 1994 to September 2, 1995. The West Hackberry Tertiary Project is one of four mid-term projects selected by the United States Department of Energy(DOE) as part of the DOE's Class 1 Program for the development of advanced recovery technologies in fluvial dominated deltaic reservoirs. Over an 82 month funding period from September 3, 1993 to July 2, 2000, Amoco and the DOE will implement a field test of the theory that air injection can be combined with the Double Displacement Process to create a tertiary oil process that is economically viable for the domestic oil industry. As part of the project, the Petroleum Engineering Department at Louisiana State University(LSU) has

been subcontracted to provide independent study and technology transfer support. The Statement of Work for the West Hackberry Tertiary Project is contained in Appendix A.

West Hackberry Field is a salt oil dome field located in Southwestern Louisiana. The project reservoir is the Oligocene Age Camerina C-1,2,3 Sands(Cam C-1,2,3) found on the West Flank of the field. Although the Cam C-1,2,3 watered out at the beginning of 1993, the air injection project is expected to produce an added 2.9 million barrels of tertiary oil over the next 15 years. A historical production plot is included on Page No.6.

2.2 Conclusions
The following conclusions have been generated during the second year of the project:
1) The pressure response seen thus far is the result of air injection and confirms the original geologic picture in both Fault Block II and Fault Block IV.
2)Early nitrogen breakthrough in Fault Block II is the result of preferential flow through a high permeability interval in the upper portion of the Cam C-1 Sand.
3)Spontaneous combustion is taking place in the reservoir as evidenced by the presence of nitrogen without oxygen in the produced gasses in Fault Block II and by the elevated temperature found in the air injectors.
4)While the potassium chloride(KCl) purge water system successfully served as a low cost alternative to a nitrogen purge system, the combination of KCl water and oxygen or carbon dioxide produced corrosion and the need to replace the tubing strings in both air injectors.
5)After a successful recompletion back to the Cam C-1,2 Sand, the Gulf Land D No.45 in Fault Block IV tested at a rate of 190 BOPD and 451 BWPD in August of 1995 after previously watering out in December of 1990. The cause of the oil production in the Gulf Land D No.45 is either due to response to air injection or due to zones now producing through a gravel pack that had previously sanded up. More production performance will be required to determine the source of the new oil production in the Gulf Land D No.45.

2.3 Recommendations
The following recommendations are presented for the upcoming year:
1)Continue air injection while monitoring reservoir performance with production data, bottom hole pressure surveys, well tests and produced oil, gas and water analyses.
2)Monitor production performance in the Gulf Land D Nos.44 and 45 to assess the timing of the planned recompletion of the Gulf Land D No.1 to the Cam C-1,2 Sand.

3.0 Introduction

The West Hackberry Tertiary Project is the field test of the concept that injecting air into a watered out oil reservoir can economically produce tertiary oil. The mechanics of project implementation involve: 1)injecting air into the crest of a watered out oil reservoir in order to fill the reservoir with a gas from the top down, 2)as the reservoir fills with air, oxygen is consumed through spontaneous combustion, 3)oil and water drain toward the base of the structure through gravity segregation and gravity drainage, and

2

WH CAM C RI SU

WEST HACKBERRY AIR INJECTION PROJECT

Oil Rate (Calendar Day) (bbls)

Gas Rate (Calendar Day) (Mscf)

Water Rate (Calendar Day) (bbls)
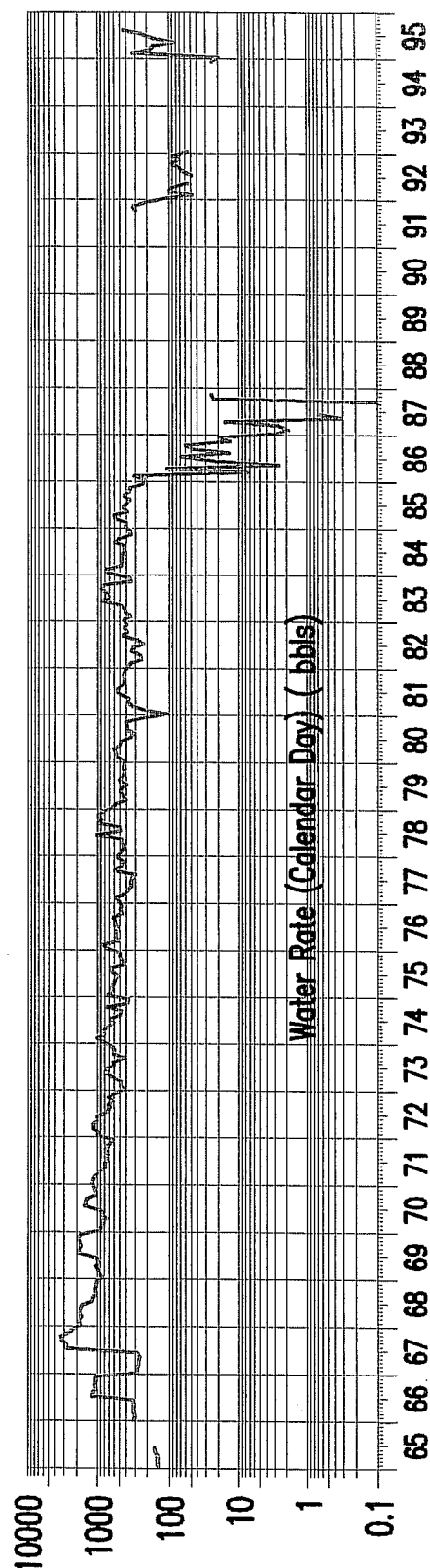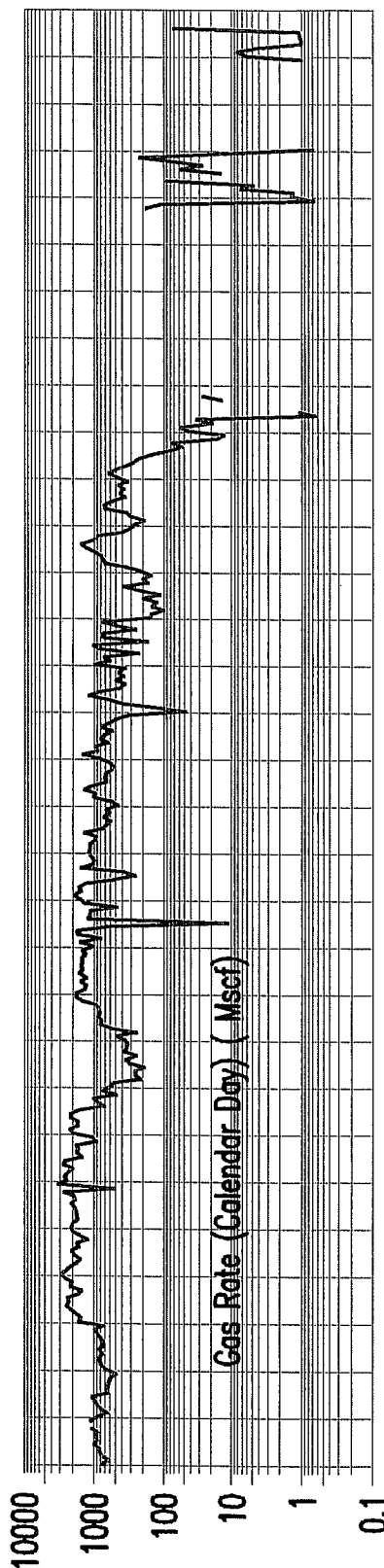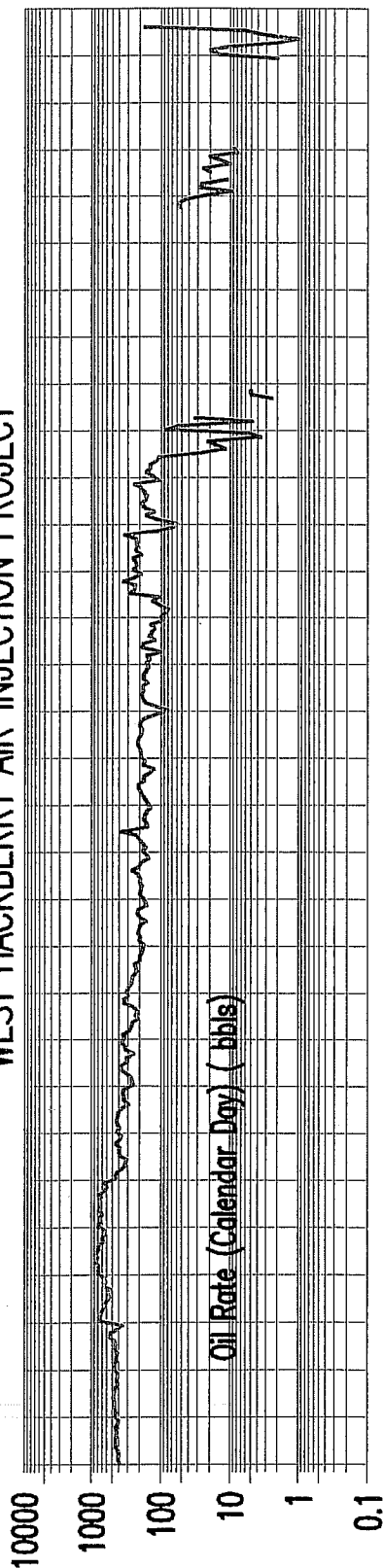
4)tertiary oil, which previously had been trapped as a residual oil saturation, is now produced in downstructure wells. In this case, the economic promise of the project is enhanced by selecting for injection the lowest cost available gas, which is air.

Activities performed thus far include laboratory tests, reservoir modeling, construction of surface facilities, air injection, reservoir monitoring, well workovers and technology transfer. Air injection began on November 17, 1994 and 457 MMSCF have been injected through August 31, 1995. Well workovers have gone as planned with repairs and recompletions performed successfully on seven wells. In addition, two workovers are now under way. Significant air compressor down time is being resolved through repairs and design modifications. A 3-D seismic survey now being shot throughout the field should enhance the understanding of the geology over the project area.

LSU's independent study is proceeding on schedule. Although technology transfer activities have been limited during the past year, these efforts will be expanded during 1996 after allowing time for some production response. The aforementioned activities have enabled air injection to be implemented in both of the project fault blocks as planned. The present status of the project is that the air injection is ongoing and production response is expected in the near future. The future direction of the project is to continue filling the reservoir with air and to monitor for production response.

4.0 Discussion

4.1 Installation and Operation of Surface Injection Facilities

Installation of the surface injection facilities was completed on November 17, 1994. The injection facilities consist of two air injection compressors, an air injection control skid, a purge water system, air and purge water injection lines and wellhead skids at the injection wells. In addition, a programmable logic controller (PLC) and remote terminal units (RTU's) are installed to control and monitor the injection facilities. On the following page are pictures of the air compressors and the water purge system.

The air compression consists of a screw compressor in series with a reciprocating compressor and has a capacity of 4.2 MMSCFD. The screw compressor compresses atmospheric air to 100 psi through two stages of compression. The reciprocating compressor compresses the 100 psi air to a final design pressure of 4300 psi through an additional 5 stages of compression. Both compressor packages are skid mounted high speed natural gas engine driven separables. The screw compressor is an Atlas Coptic ZR-6 "oil-less" compressor driven by a Waukesha 5108 GL "lean burn" engine. The reciprocating compressor is an Ariel JGK-4 compressor driven by a Waukesha 9390 GL "lean burn" engine. The Waukesha GL engines were chosen to meet emissions regulations without the installation of catalytic converters. A diester synthetic lubricant with a flash point of 500 degrees F and an auto-ignition temperature of 770 degrees F is used to lubricate the reciprocating compressor to prevent deposits in the piping which can cause detonations and explosions. The primary causes of explosions in high pressure air

KCl Water Purge System
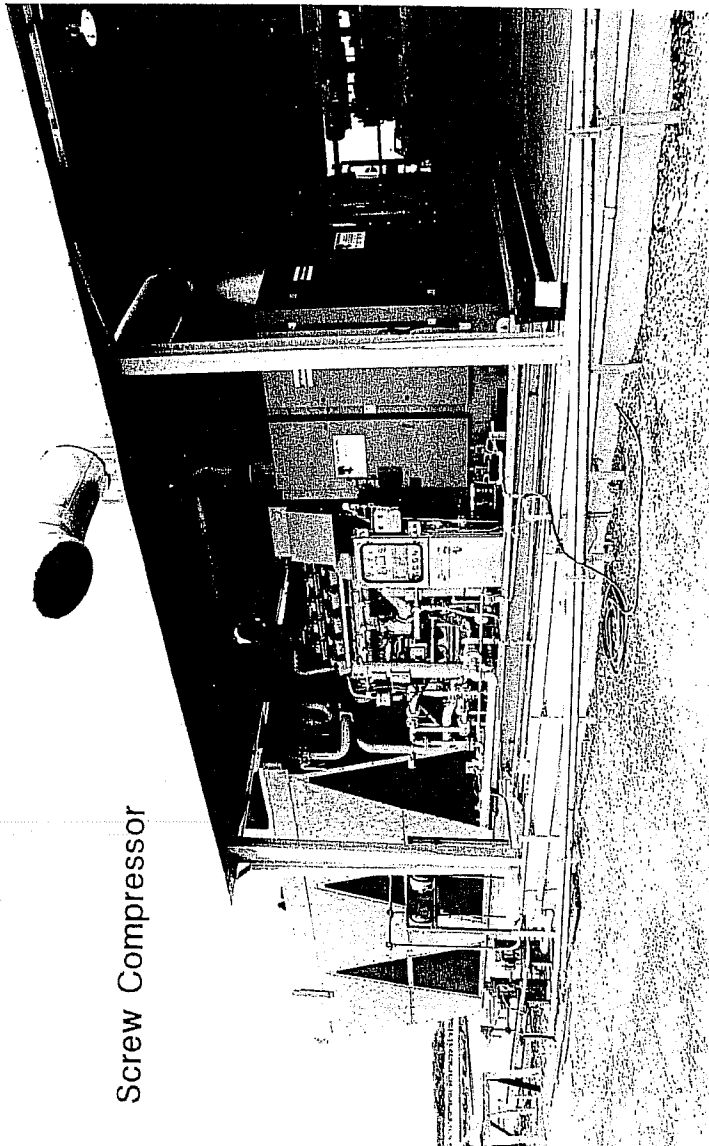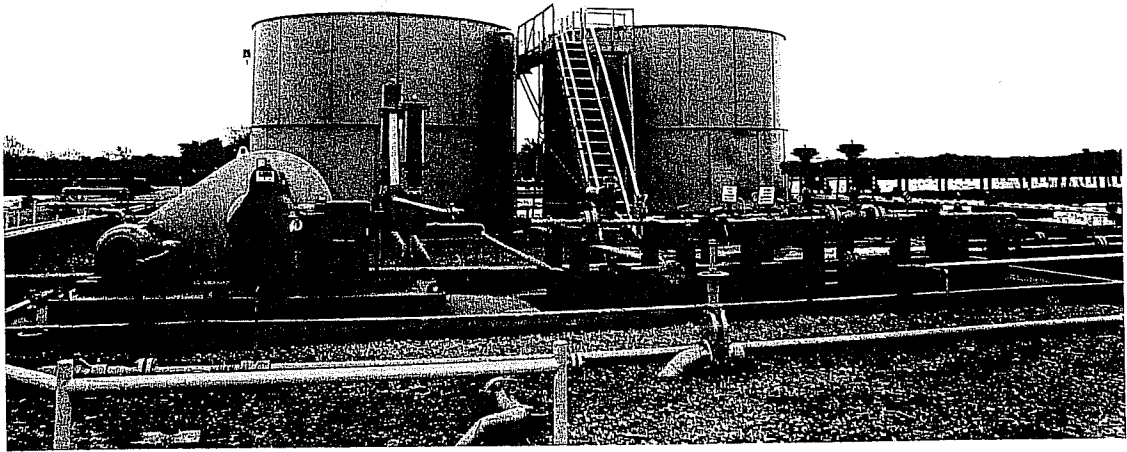
Screw Compressor
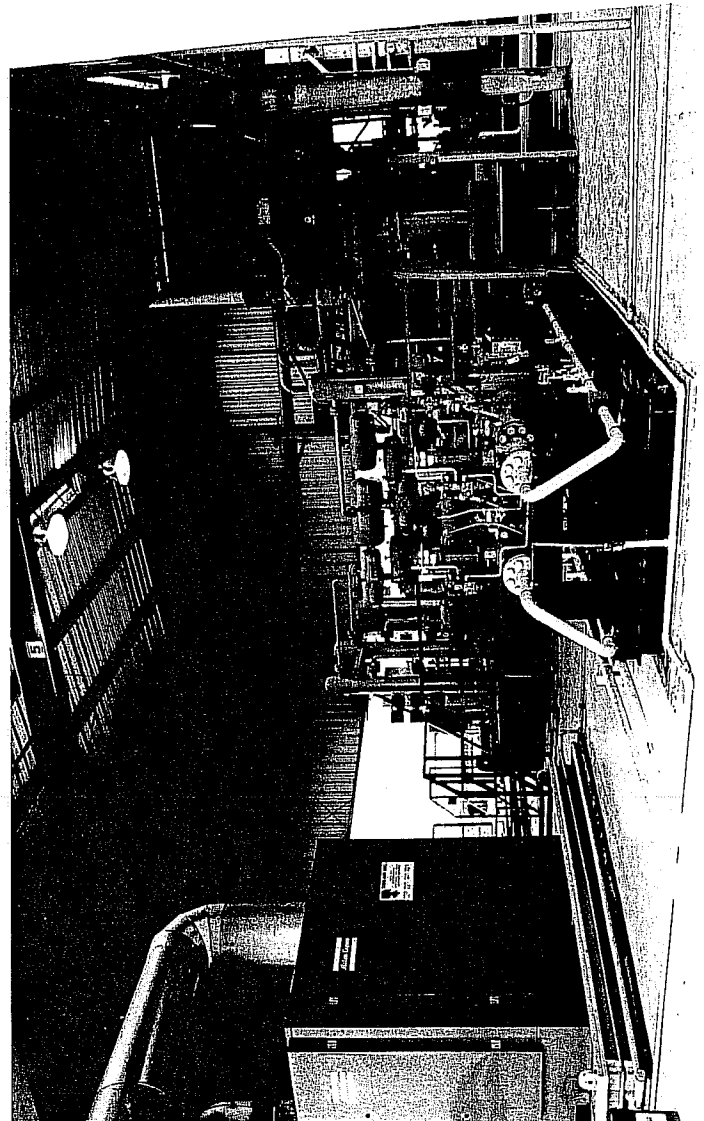
Reciprocating Compressor

compression systems are: 1)the use of hydrocarbon based lubricants which "break down" under high temperatures and form deposits which ignite due to the lower auto-ignition temperatures and 2)forming of deposits due to over lubrication with any type of lubricant. Two smaller compressor packages in series, rather than one large compressor, was chosen for this installation for several reasons. The first reason was logistics. The location is a remote marsh environment with limited land area on which to install compressors and limited access over two weight-restricted wooden pile bridges and limestone roads. By choosing two smaller units, trucks and cranes were used which could handle the load capacity and still were able to access the location as well as being able to use two existing abandoned compressor foundations on the only available dry land in the area. Another reason for choosing the screw compressor to reciprocating compressor installation was the operating advantages of the "oil-less" screw compressor over a reciprocating compressor for the lower stages of compression. Being that the compressed air does not come in contact with lubricating oil, the water vapor in the air that condenses during compression can be dumped on the ground in an environmentally sound manner. This is a real advantage because the majority of the water vapor is condensed in the first two stages of compression and this can be as much as 600 gallons per day in South Louisiana in the summer. Also, an "oil-less" screw compressor reduces operating cost by not requiring a synthetic lubricant at $25 per gallon. At the time of design it was also estimated that a screw compressor would be more reliable. Operating experience to date has proven this to be true as most of the downtime due to compressor mechanical problems has been with the reciprocating compressor. Finally, there was a cost and equipment availability advantage in choosing the screw compressor to reciprocating compressor installation over one large reciprocating compressor.

The air injection control skid is located at the compressor station and has an orifice meter and an actuated control valve for each injection well. A PLC controls the air injection rate to each well and the rate, pressure and temperature is monitored on the Hackberry automation system through an RTU. The Hackberry automation system can be viewed from Amoco's Houston office in addition to the Hackberry field office.

The water purge system consists of an electric motor driven triplex plunger pump with a capacity of 21 gallons per minute at 4300 psi discharge pressure, a 1000 barrel water storage tank and a control skid similar to the air control skid at the compressor station. The purpose of the purge water system is to load the injection wells with water if there is an interruption in air injection. This serves to cool the near-wellbore area from the heat of combustion, help prevent the backflow of hydrocarbons into the wellbore and to prevent explosions in the injector by acting as a cushion between hydrocarbons and air when air injection resumes. The purge water is 2% potassium chloride(KCl) by weight to prevent permeability damage due to the swelling of fresh water sensitive clays in the reservoir. The PLC is programmed to start the purge water pump 30 minutes after the compressors shut down, control the rate to each well at 10.5 gpm and shut off after 60 barrels of water is pumped into each air injector. Normal operating practice was to purge the wells a second time using a manual override before resuming air injection if the compressors were down for several days. Purging operations were required early in the

project life when combustion was in the near-wellbore area and were discontinued in June of 1995.

The air and purge water lines are 2-3/8" O.D., .436" wall thickness, ASTM A106 Grade B seamless carbon steel line pipe coated with TGF-3 for external corrosion protection. Design pressure is 4730 psi with a 1/8" corrosion allowance. All lines are run above water level and secured on wooden pile pipe racks. Due to safety considerations, the lines follow remote routes that minimize contact with operating personnel. Canal crossings are buried and road crossings are cased and buried.

Each injection well is equipped with a wellhead skid. The skid consists of a wellhead scrubber to catch condensed liquids, an orifice meter to measure the air injection rate, a turbine meter to measure the purge water injected and pressure operated control valves to control system pressure and act as a secondary shut-down valve. The wellhead is equipped with dual wing valves, one side for the air injection line and the other side for the purge water line. Each wing also has a piston check valve to keep the well under control in the event of a line break. In the event of a hole in tubing which could cause casing damage due to the high surface injection pressures, the air side has a fail closed safety shut-down valve which closes if the casing pressure reaches 1200 psi. Injection pressure, rate, temperature and casing pressure are monitored on the Hackberry automation system through an RTU.

4.2 Well Workovers

4.2.1 Well Workovers in Fault Block II
On the following page is a structure map for the top of the Cam C-1 Sand which depicts the location of wells involved in the air injection project. In April of 1995, the Watkins No.18 was recompleted to the Cam C-1,2,3 Sand. In the July of 1995, the Watkins No.3 was squeezed twice with cement to isolate the Cam C-1,2,3 from the Bol-3. The Watkins No.3 had seen nitrogen production due to communication between the well's completion interval, the Bol-3, and the air injection project sand, the Cam C-1,2,3. After pumping the cement squeezes, the Watkins No.3 was temporarily abandoned. Currently, a rig is repairing the Watkins No.16, an air injection well, to replace corroded tubing. In order to save on repair expense, the tubing in the Watkins No.16 will be replace with used tubing from an offset well, the Watkins No.5.

4.2.2 Well Workovers in Fault Block IV
In August of 1995, the Gulf Land D No.45 was successfully recompleted downhole from the Marg Howei to the Cam C-1,2 Sand to accelerate production response in light of lower than expected air injection volumes. The Gulf Land D No.45 had previously watered out in December of 1990 in the identical perforation interval in the Cam C-1,2 while producing less than 10 BOPD with greater than a 95% water cut. A production plot for the Gulf Land D No.45 is included on Page No.12. On August 17, 1995, the Gulf
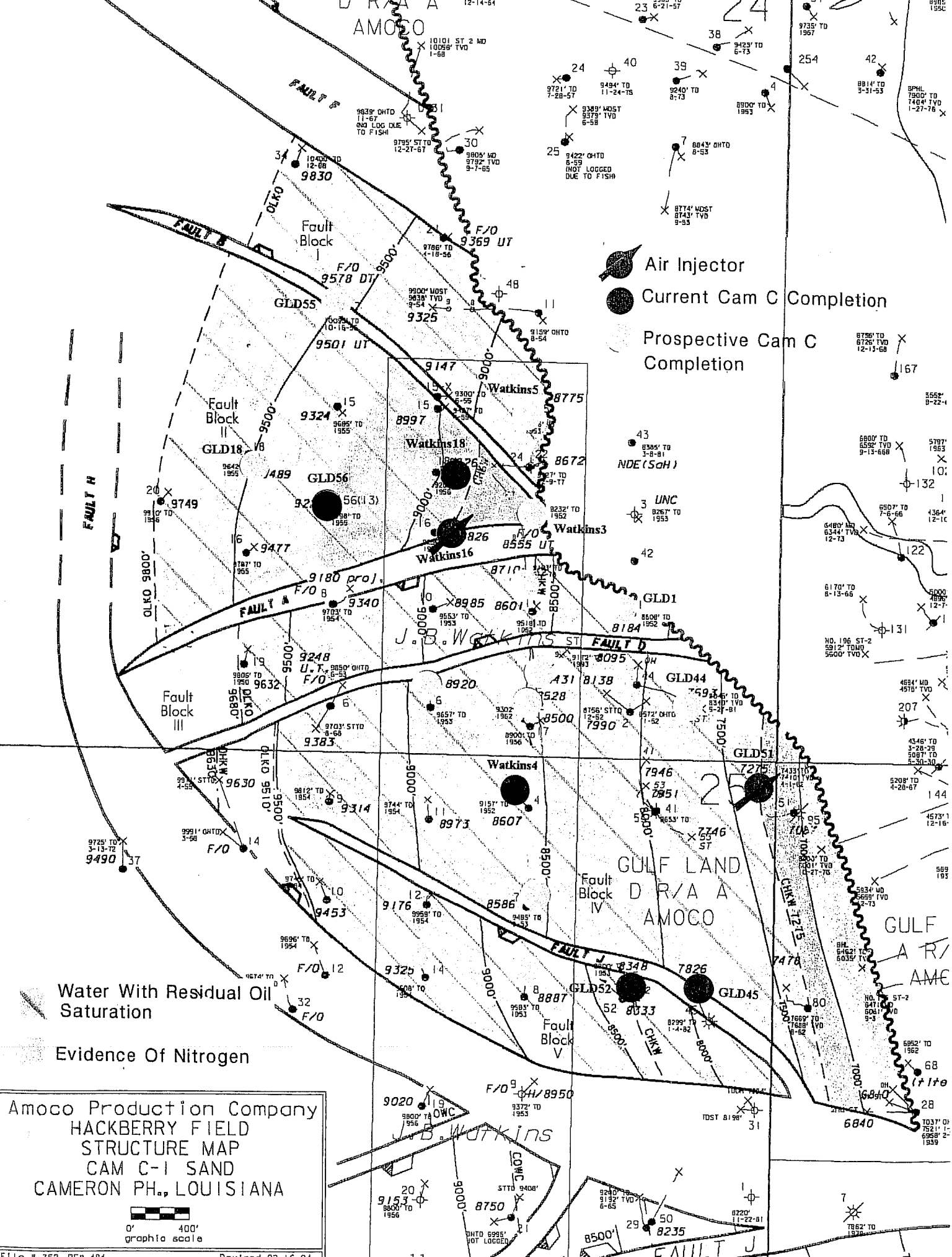
Air Injector

Current Cam C Completion

Prospective Cam C Completion

Water With Residual Oil Saturation

Evidence Of Nitrogen

Amoco Production Company
HACKBERRY FIELD
STRUCTURE MAP
CAM C-1 SAND
CAMERON PH., LOUISIANA

0'   400'
graphic scale
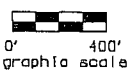
GULF LAND D #45 (CAM C-1,2 SAND)
WEST HACKBERRY FIELD
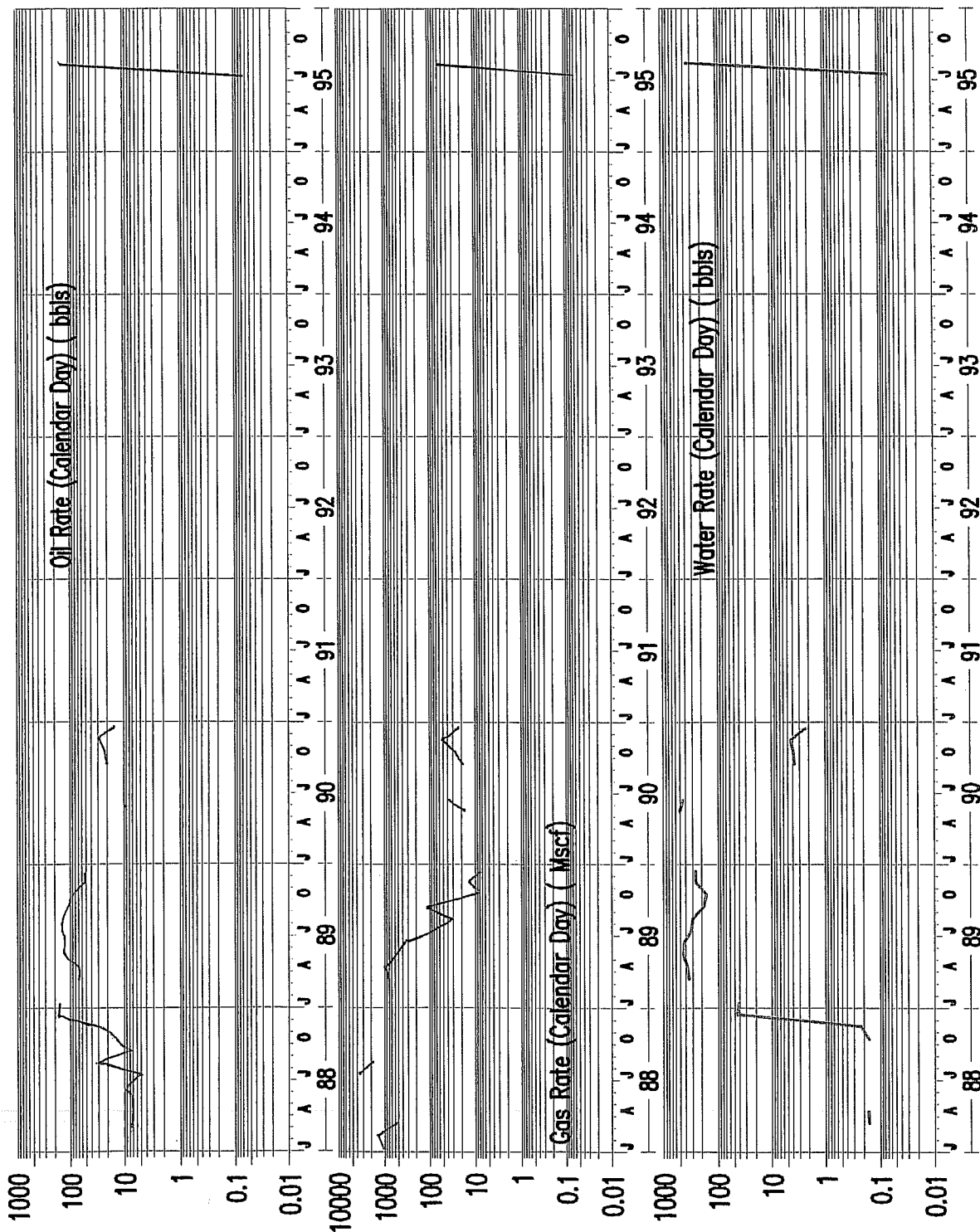
Oil Rate (Calendar Day) (bbls)

Gas Rate (Calendar Day) (Mscf)

Water Rate (Calendar Day) (bbls)

MAF Thu Sep 21 10:58:16 1995

Land D No.45 tested gas lifting at a rate of 190 BOPD, 451 BWPD and 25 MSCFD with no evidence of nitrogen production.

Currently, a rig is recompleting the Gulf Land D No.44 to the Cam C-1,2 Sand. The Gulf Land D No.44 is slightly upstructure to the Gulf Land D No.45. The recompletion of the Gulf Land D No.44 to the Cam C-1,2 will: 1)provide an opportunity to validate the new oil production in the Gulf Land D No.45 and 2)provide another opportunity to accelerate production response in Fault Block IV in light of less than expected air injection volumes. Depending upon future production response in the Gulf Land D Nos.44 and 45, the Gulf Land D No.1 may be recompleted to the Cam C-1,2 Sand during the next twelve months. The recompletion of the Gulf Land D No.1 was included in the original project design.

4.3 Responding to Project Performance
Project implementation requires monitoring performance, recognizing reservoir response and making modifications to optimize performance. The following sections, 4.3.1 through 4.3.6, describe project performance and modifications to the original project design.

4.3.1 Pressure Response
A minimum of three bottom hole pressure surveys are taken every quarter to assess the effect of air injection on reservoir pressure. On the next two pages are tables and plots of reservoir pressure versus time representing historical pressure data of over the 40 year production history of the reservoir. In Fault Block II, pressure data collected since the start of air injection indicates that reservoir pressure had increased by 50 psi to 3350 psi and then fallen to 3311 psi over a prolonged period of production without injection. In Fault Block IV, bottom hole pressure surveys indicate that the reservoir pressure had increased by over 200 psi since the start of air injection.

The pressure response seen to date is the result of air injection and confirms the original geologic picture in both Fault Block II and Fault Block IV.

4.3.2 Early Nitrogen Breakthrough in Fault Block II
In Fault Block II, nitrogen breakthrough was detected in the Gulf Land D No.56 after injection of only 31 MMSCF of air into the Watkins No.16. Shortly thereafter, nitrogen was also noted in the Watkins No.3 and Watkins No.18. After nitrogen breakthrough, 26.5%, 20.0% and 6.8% nitrogen were measured in gas samples collected from the Gulf Land D No.56, Watkins No.3 and Watkins No.18, respectively. Essentially no oxygen and 0.6%-1.6% carbon dioxide were measured in the nitrogen bearing gas samples.

The only plausible explanation for early nitrogen breakthrough in the Gulf Land D No.56 after the injection of 31 MMSCF of air is that almost all of the injected air must have channeled through a high permeability layer. On Page No.16 is an electric log from the Watkins No.16 with sidewall core descriptions posted on the log. The side wall core descriptions show that coarse to medium grain sand is found in the upper portion of the Cam C-1 Sand while the remainder of the Cam C-1,2,3 is composed of fine to very fine

Fault Block	Well	Cam B-1					Cam C-1					Cam C-2,3				
		Pressure	9000'Press.	Date	Depth	Temp.(F)	Pressure	9000'Press.	Date	Depth	Temp.(F)	Pressure	9000'Press.	Date	Depth	Temp.(F)
I	Watkins #5						3711 psi	3839 psi	6/55	8607'						
							2407 psi	2531 psi	4/83	8612'	228					
							3124 psi	3217 psi	6/91	8800'	208					
	Watkins #15A															
	Watkins #22	2912 psi	3026 psi	12/77	8645'		3880 psi	3847 psi	1/55	9100'		2943 psi	3058 psi	12/77	8751'	
	GLD #11	3413 psi	3413 psi	4/64	9000'		3135 psi	3415 psi	3/56	8150'		2974 psi	2974 psi	4/64	9000'	
							3160 psi	3500 psi	3/60	9000'						
							2843 psi	3125 psi	3/61	8000'						
							2909 psi	3378 psi	3/62	8000'						
	GLD #17	3700 psi	3700 psi	3/56	9000'											
	GLD #21															
	GLD #34															
II	Watkins #15						2887 psi	2887 psi	10/76		200	2217 psi	2239 psi	7/82	8930'	209
							3233 psi	3271 psi	5/94	8911'		2150 psi	2230 psi	3/80	8750'	
												2115 psi	2134 psi	11/81	8940'	
												3156 psi	3188 psi	6/91	8899'	204
	Watkins #18						2899 psi	2922 psi	8/83	8950'	210					
							3058 psi	3168 psi	8/91	8775'	201					
							3224 psi	3271 psi	3/95	8900'	207					
	GLD #56(13)						3780 psi	3647 psi	3/56	9400'						
							3500 psi	3500 psi	3/60	9000'		3350 psi	3350 psi	6/64	9000'	
							3429 psi	3429 psi	3/61	9000'						
							3375 psi	3375 psi	3/62	9000'						
							3436 psi	3301 psi	5/94	9320'	206					
							3468 psi	3550 psi	2/95	9200'	205					
							3473 psi	3321 psi	6/95	9319'						
							3392 psi	3311 psi	8/95	9167'	206					
	GLD #15	2772 psi	2868 psi	4/64	8800'		3624 psi	3688 psi	9/55	8800'		3247 psi	3247 psi	3/62	9000'	
	GLD #16						3460 psi	3780 psi	3/56	9000'		3357 psi	3357 psi	6/64	9000'	
							3170 psi	3410 psi	3/60	8500'		3339 psi	3339 psi	11/81	9504'	
							3163 psi	3371 psi	3/61	8500'		4010 psi	3878 psi	9/55	9400'	
												3900 psi	3768 psi	3/56	9400'	
	GLD #18											2740 psi	2922 psi	3/62	8500'	
												3240 psi	3460 psi	6/64	8500'	
												3825 psi	3825 psi	3/56	9000'	
												3330 psi	3330 psi	3/60	9000'	
												3293 psi	3293 psi	3/61	9000'	
												3256 psi	3256 psi	3/62	9000'	
	GLD #20	4000 psi	3777 psi	3/56	9697'											
III	Watkins #1						4110 psi	4227 psi	5/52	8635'		2300 psi	2382 psi	11/68	8744'	
	Watkins #10	623 psi	751 psi	3/69	8600'		1968 psi	2247 psi	6/78	8400'	200	1506 psi	1702 psi	4/77	8800'	
		2539 psi	2554 psi	4/65	8952'		2892 psi	2878 psi	3/64	9044'						
	GLD #1						3607 psi	3985 psi	12/54	8170'						
							3505 psi	3766 psi	9/55	8170'						
	GLD #8	1826 psi	1826 psi	1/55	9000'		3415 psi	3694 psi	3/56	8150'						
		2140 psi	2140 psi	3/56	9000'											
		770 psi	770 psi	3/60	9000'											
		547 psi	605 psi	3/61	7400'											
		1525 psi	1525 psi	3/62	9000'											
		646 psi	646 psi	2/63	9000'											
		812 psi	812 psi	4/64	9000'											
	GLD #19						3700 psi	3700 psi	3/56	9000'						
IV	Watkins #2															
	Watkins #4											2016 psi	2176 psi	7/73	8500'	
												1952 psi	2042 psi	5/91	8749'	195
												2336 psi	2470 psi	9/94	8716'	198
												2386 psi	2518 psi	2/95	8716'	198
												2487 psi	2593 psi	5/95	8769'	
												2525 psi	2643 psi	8/95	8749'	199
	Watkins #6															
	Watkins #7															
	Watkins #11											2400 psi	2364 psi	9/69	9111'	
												1478 psi	1444 psi	2/80	9100'	190
	Watkins #17															
	Watkins #17ST															
	GLD #2											3482 psi	3770 psi	12/54	9000'	
												3178 psi	3782 psi	9/55	8244'	
												3490 psi	3543 psi	3/56	8250'	
												3290 psi	3330 psi	11/57	8200'	
												3000 psi	3090 psi	3/60	8150'	
												2928 psi	2980 psi	3/61	8250'	
												2839 psi	2901 psi	3/62	8000'	
												2857 psi	2918 psi	6/64	8000'	
	GLD #6						3831 psi	3750 psi	1/55	9250'		3202 psi	3084 psi	7/82	9369'	184
							3740 psi	3660 psi	3/56	9250'		2950 psi	2905 psi	6/64	9100'	
							3230 psi	3184 psi	3/60	9250'						
							3098 psi	3003 psi	3/61	9300'						
							3013 psi	3013 psi	3/62	9000'						
	GLD #6ST															
	GLD #9						3754 psi	3754 psi	1/55			1838 psi	1691 psi	8/78	9450'	200
							3650 psi	3650 psi	3/56	9000'						
							3190 psi	3190 psi	3/60	9000'						
							3002 psi	3002 psi	3/61	9000'						
							2937 psi	2937 psi	3/62	9000'						
							2764 psi	2899 psi	1/63	8600'						
							2825 psi	2825 psi	2/64	9000'						
	GLD #12	3849 psi	3783 psi	1/55	9200'		2792 psi	2881 psi	2/06	9147'	228					
		3324 psi	3314 psi	3/56	9030'											
		2070 psi	2070 psi	3/60	9000'											
		1671 psi	1671 psi	3/61	9000'											
		1925 psi	1925 psi	3/62	9000'											
	GLD #14ST	761 psi	754 psi	7/77	9538'											
	GLD #41	841 psi	855 psi	7/80	7893'		1752 psi	2218 psi	7/80	7998'		1724 psi	2031 psi	7/80	8041'	
							1771 psi	2225 psi	9/81	8024'	190					
							1715 psi	2187 psi	11/81	7985'		1812 psi	2141 psi	4/88	7982'	161
	GLD #44															
	GLD #45															
	GLD #51						1896 psi	2636 psi	7/94	7312'	183	1689 psi	2375 psi	7/94	7417'	186
							1896 psi	2630 psi	7/94	7307'		1673 psi	2360 psi	7/94	7427'	187
							1932 psi	2653 psi	7/94	7367'	185					
							1857 psi	2566 psi	8/94	7377'	186					
V	Watkins #8	433 psi	500 psi	6/91	8797'	180						1975 psi	1975 psi	7/73	9000'	
	Watkins #12						2109 psi	2109 psi	4/79	9000'						
	Watkins #14	842 psi	840 psi	7/73	9150'											
	GLD #5						1750 psi	1950 psi	2/77			3490 psi	3575 psi	12/54	8440'	
												3440 psi	3598 psi	9/55	8440'	
												3400 psi	3751 psi	3/56	8150'	
												3290 psi	3350 psi	11/57	8400'	
												3010 psi	3070 psi	3/60	8400'	
												2843 psi	2912 psi	3/61	8000'	
												2779 psi	2937 psi	3/62	8250'	
												2660 psi	2874 psi	6/64	8250'	
												2618 psi	2858 psi	3/65	8250'	
												2339 psi	2509 psi	3/68	8470'	
												2245 psi	2415 psi	3/70	8472'	
	GLD #10	1106 psi	1101 psi	1/74	9398'	194	3759 psi	3759 psi	1/55	9000'						
							3560 psi	3560 psi	3/56	9000'						
							3140 psi	3140 psi	3/60	9000'						
							3049 psi	3049 psi	3/61	9000'						
							2933 psi	2933 psi	3/62	9000'						
							2833 psi	2678 psi	2/66	9489'	196					
	GLD #52						2407 psi	2675 psi	8/94	8386'	193					
							2512 psi	2803 psi	2/95	8386'						
							2655 psi	2855 psi	5/95	8386'	194					
							2577 psi	2683 psi	8/95	8386'	195					
							2594 psi									

16

BHP vs. Time(W. Hackberry Air Injection Project)

Legend:
- FB's I & II
- FB's III, IV

Y-axis: SIBHP(psi) at -9000' Datum

ENTIAL MILLIVOLTS	RESISTIVITY OHMS M⁴/M	RESISTIVITY OHMS

- → 20 ← +

0	18" NORMAL	10	0	16'LATERAL
0		100	0	
0		1000	0	
0	9'LATERAL	10		
0		100		
0		1000		
0	18" AMPLIFIED NORMAL	20		16'AMPLIFIED LATER

CAM C-1,2,3

8850

8900

8950

DEPTH FROM	TO	FORMATION	POROSITY OF SATURATION TEST SAMPLE	PERCENT OIL SATURATION	PERCENT WATER SATURATION	CHLORIDE MG/LITER	RESISTIVITY IN OHM-METERS	ETHER CUT	FLUORESCENCE OF ETHER CUT
8845		Silt,Laly.Cons.,Sl.Lmy.	Insufficient Sample				–	V.Ft.	Ft.
8849		Sand,M.Gr.,Laly.Cons., Argil.	23.6	3.3	82.1	12,050		Ft.	Fr.
8858		Sand,F.-M.Gr.,Laly.Cons.	Insufficient Sample						
8861		Sand,M.Gr.,Laly.Cons., Sl.Lmy.	35(A)	26.0	29.6	5200	–	V.Gd.	Ex.
864		Sand,M.-C.Gr.,Laly.Cons. V.Sl.Lmy.	35(A)	29.8	49.6	3050	–	V.Gd.	Ex.
867		Sand,F.-M.Gr.,Laly.Cons. V.Sl.Lmy.	35(A)	25.1	36.4	7400	–	V.Gd.	Ex.
8871		Ditto	36.4	26.6	32.7	3500	–	V.Gd.	Ex.
8875		Sand,V.F.Gr.,Laly.Cons., Sl.Lmy.	33.7	8.1	68.2	4050	–	Fr.	Gd.
877		Sand,V.F.-F.Gr.,Laly.Cons. V.Sl.Lmy.	33.2	7.3	56.4	8650	–	Fr.	Gd.
8883		Sand,V.F.Gr.,Laly.Cons., Lmy.	36.4	8.2	54.9	3900	–	Fr.	V.Gd.
8885		Ditto	35(A)	24.3	27.1	4150	–	Gd.	Ex.
8891		Ditto	35(A)	16.9	37.6	2600	–	Gd.	Ex.
8893		Ditto	35(A)	24.0	25.0	2900	–	Gd.	Ex.
8895		Sand,V.F.Gr.,Laly.Cons. V.Sl.Lmy.	35(A)	21.6	45.2	1550	–	V.Gd.	Ex.
8897		Sand,V.F.Gr.,Laly.Cons. V.Sl.Lmy.	Insufficient Sample				–	V.Gd.	Ex.
8902		Shale,Soft,V.Sl.Silty, V.Sl.Lmy.	N.T.	N.T.	N.T.	N.T.	–	0	V.Ft.
8905		Sand,V.F.Gr.,Laly.Cons., Lmy.	35(A)	18.6	50.3	3400	–	Gd.	Ex.
8907½		Ditto	Insufficient Sample				–	Fr.	Gd.
8922½		Shale,Soft,V.Sl.Lmy.	N.T.	N.T.	N.T.	N.T.	–	0	V.Ft.
8926		Shale, Soft	N.T.	N.T.	N.T.	N.T.	–	0	V.Ft.
8934		Shale, V.Sl.Lmy.	N.T.	N.T.	N.T.	N.T.	–	0	V.Ft.
8941		Sand,V.F.Gr.,Laly.Cons. Sl.Silty,Sl.Lmy.	Insufficient Sample				–	Gd.	Ex.
8947		Shale,Soft,V.Silty, V.Sl.Lmy.	Insufficient Sample				–	0	V.Ft.
8949		Sand,V.F.Gr.,Laly.Cons. Lmy.	Insufficient Sample				–	Ft.	Fr.
8951		Sand,V.F.-F.Gr.,Laly. Cons.,V.Sl.Lmy.	33.5	11.0	54.9	2950	–	Ft.	Fr.
8959		Ditto	33.3	10.0	59.4	4900	–	Ft.	Fr.
8962		Sand,V.F.-F.Gr.,Laly. Cons.,Sl.Lmy	Insufficient Sample				–	Gd.	Ex.

ELECTRIC WELL LOG

COMPANY SHELL OIL COMPANY	Location 1500'N & 2300 W Fr SE¼ Sec 24
FILE	
WELL MRS J B WATKINS #16	
FIELD WEST HACKBERRY	
COUNTY CAMERON STATE LOUISIANA	
SEC 24 TWP 12 S RGE 11 W	(Feynes) Elevation: D.F. ___ KB. ___ Grd ___
SURVEY	

sand. Grain size is typically an indicator of permeability with larger grain size (medium to coarse grain) having greater permeability than smaller grain size. Assuming a 50% gas saturation and a 24 acre area surrounding the aforementioned wells in Fault Block II, the air would have flooded an average of only two feet of thickness for all three wells to have seen nitrogen breakthrough after injection of 46 MMSCF of air through April 1, 1995.

All or almost all of the air being injected into the Watkins No.16 appears to have gone into the high permeability interval in the upper portion of the Cam C-1. To rectify this situation, the upper portion of the Cam C-1 will be squeezed with cement during the currently ongoing repair of the Watkins No.16. Henceforth most, if not all of the air injected into the Watkins No.16 will be injected into the lower portion of the Cam C-1 and the Cam C-2,3.

4.3.3 Evidence of Combustion
The following sections, 4.3.3.1 through 4.3.3.3, describe the three pieces of evidence that have proven that combustion is taking place in the reservoir.

4.3.3.1 Lack of Oxygen in Nitrogen Breakthrough Gas
When nitrogen was detected in the Gulf Land D No.56, Watkins No.3 and Watkins No.18, only a trace of oxygen was noted in the gas analyses. The notable lack of oxygen is attributable to oxygen consumption resulting from in-situ combustion.

4.3.3.2 Injection Pressure Increase in the Gulf Land D No.51(air injector)
On a repeated basis, the Gulf Land D No.51 has exhibited a 500-700 psi increase in wellhead injection pressure after about five days of injection. Each time the air compressors were restarted, the injection pressure in the Gulf Land D No.51 would increase from 1700 or 1800 psi up to 2300-2500 psi after five days of continuous injection. The pressure increase is observable on a plot of injection rates and pressures on Page No.18. After injection ceased and then restarted, injection pressure would return to the 1700-1800 psi range. Pressure increases similar to those seen in the Gulf Land D No.51 have been noted in other air injection projects and are caused by the start of high temperature combustion. This phenomena has been noted in the Society of Petroleum Engineers(SPE) paper entitled "Initiation of an In-Situ Combustion Project in a Thin Oil Column Underlain by Water", in the October, 1982, issue of Journal of Petroleum Technology(JPT) on Page No.2241. High temperature combustion can generate a rapid release of combustion gasses which could then cause an increase in injection pressure. When air injection ceased, the source of oxygen was interrupted and high temperature combustion stopped. When air injection restarted, injection pressure returned to the 1700-1800 psi level. Although no pressure increase has been noted in the Watkins No.16, the lack of increase in injection pressure is probably due to the much lower injection rates in the Watkins No.16(500 MSCFD) when compared with the injection rates in the Gulf Land D No.51(3300 MSCFD). The air injection rates in each well were restricted to avoid exceeding the critical injection rate.

Air Injection Rate & Wellhead Pressure
Watkins No.16

Wat16InjRate
Wat16WHP

Wellhead Pressure (psi)

Rate (MSCFD)

MSCFD & PSI

4000
3500
3000
2500
2000
1500
1000
500
0

11/15/94
12/2/94
12/19/94
1/5/95
1/22/95
2/8/95
2/25/95
3/14/95
3/31/95
4/17/95
5/4/95
5/21/95
6/7/95
6/24/95
7/11/95
7/28/95
8/14/95
8/31/95
9/17/95
10/4/95
10/21/95
11/7/95
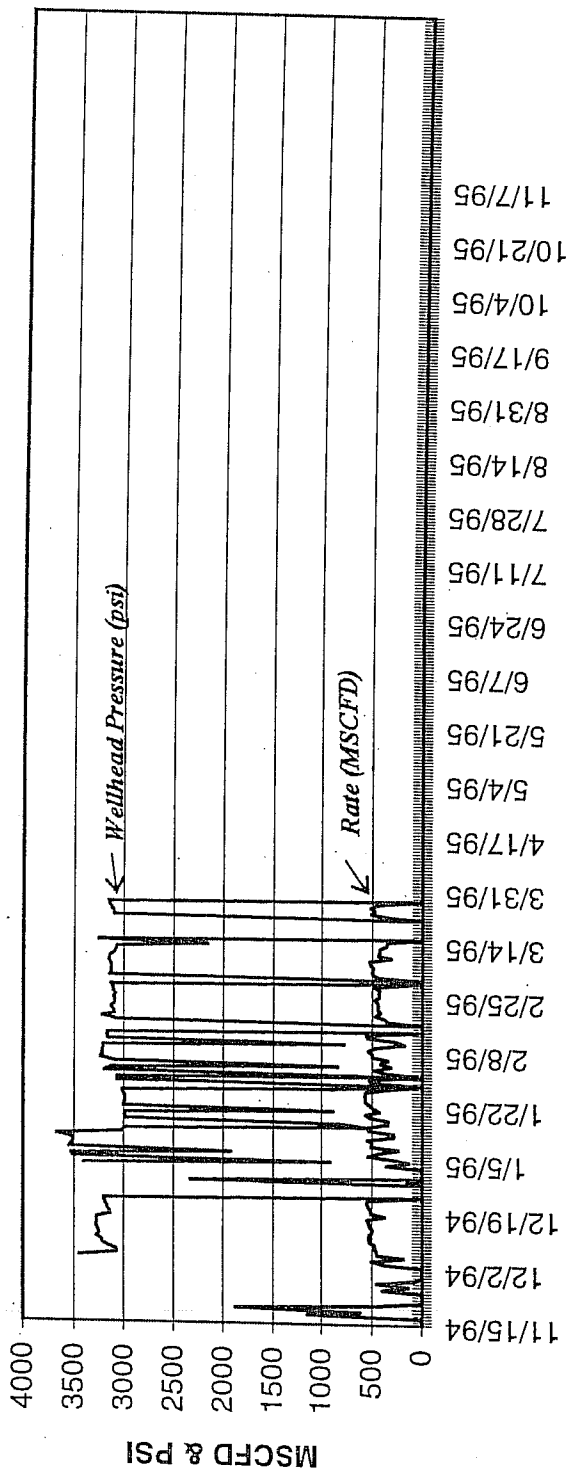
Air Injection Rate & Wellhead Pressure
Gulf Land D No.51

GLD51InjRate
GLD51WHP

Rate (MSCFD)

Wellhead
Pressure
(psi)

MSCFD & PSI

4500
4000
3500
3000
2500
2000
1500
1000
500
0

11/15/94
12/2/94
12/19/94
1/5/95
1/22/95
2/8/95
2/25/95
3/14/95
3/31/95
4/17/95
5/4/95
5/21/95
6/7/95
6/24/95
7/11/95
7/28/95
8/14/95
8/31/95
9/17/95
10/4/95
10/21/95
11/7/95
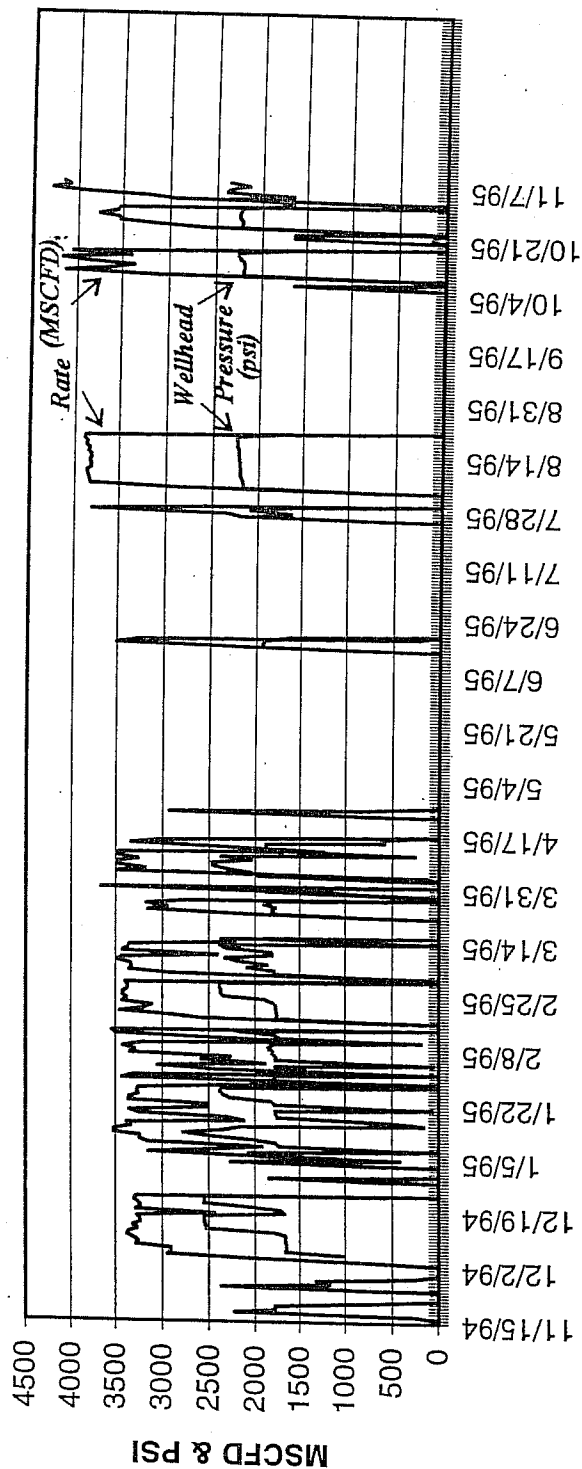
Cumulative Air Injected vs. Time
West Hackberry Air Injection Project
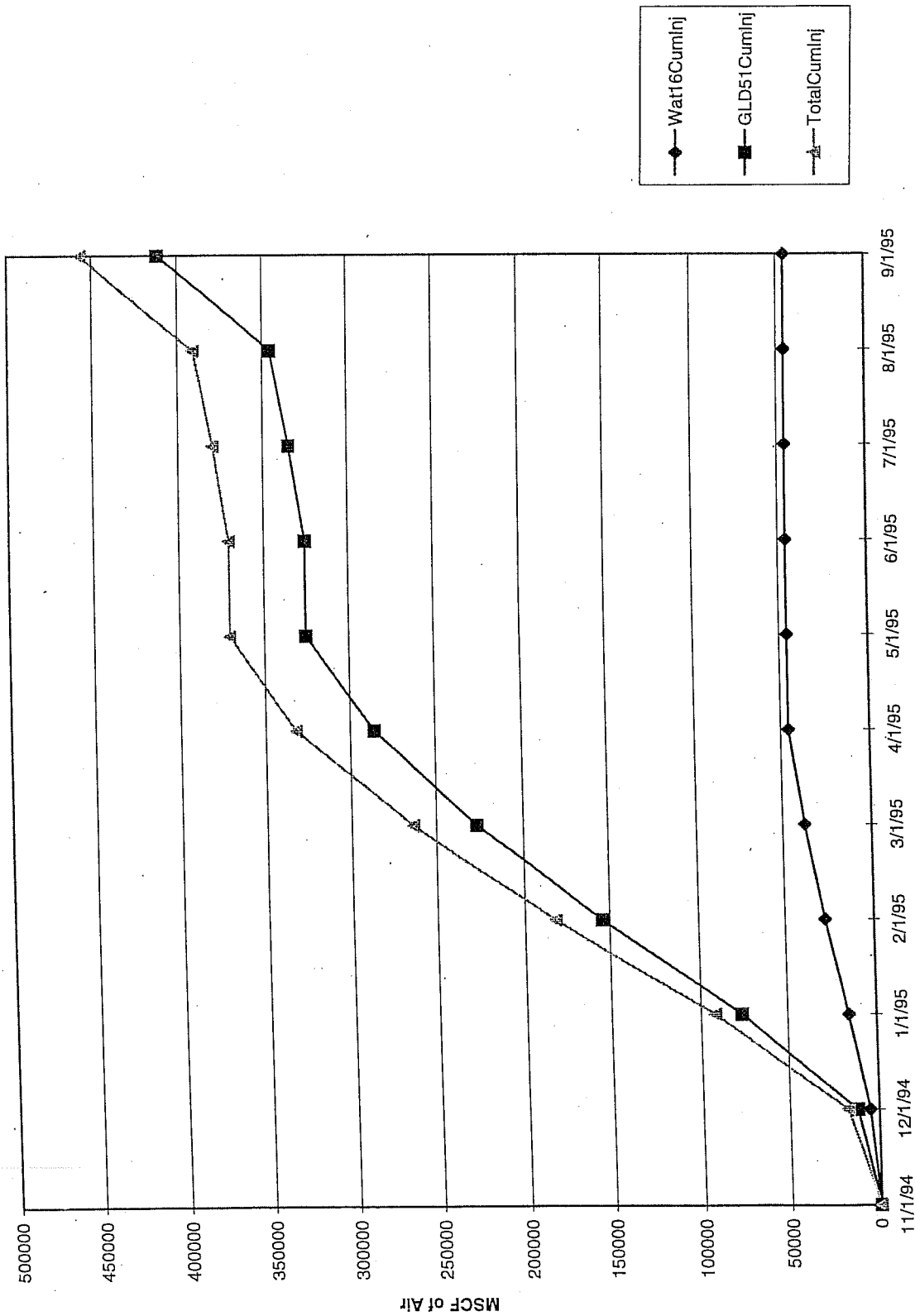
4.3.3.3 Elevated Temperature Found in Air Injectors

On March 28, 1995, a tool was run on slickline into each of the air injection wells to measure the temperature about 24 hours after the wells had stopped air injection and purge water had been pumped. The temperature of the Watkins No.16 was 298 degrees Fahrenheit at a depth of 8888', near the middle of the perforations. Up inside the tubing at a depth of 8680', the temperature was 202 degrees Fahrenheit. Prior to air injection in the Watkins No.16, the reservoir temperature in the Cam C-1,2,3 was 204 degrees Fahrenheit. A post air injection bottom hole temperature which is 94 degrees Fahrenheit higher than reservoir temperature is the result of combustion in the reservoir.

The temperature tool run in the Gulf Land D No.51 recorded the following temperatures:

7328'	176 degrees F	7390'	228 degrees F
7367'	190 degrees F	7417'	202 degrees F
7383'	218 degrees F	7446'	190 degrees F

A log section is included on Page No.21 which shows the location of the temperature measurements in the Gulf Land D No.51. Prior to air injection, the reservoir temperature in the Cam C-1,2,3 in the Gulf Land D No.51 was 186 degrees Fahrenheit. In air injection operations, oxygen is expected to burn the near-wellbore oil first and thereafter farther and farther from the wellbore. A much greater volume of air has been injected into the Gulf Land D No.51(411 MMSCF) than into the Watkins No.16(46 MMSCF), theoretically burning a much greater volume surrounding the Gulf Land D No.51 wellbore. An indicator that this is indeed occurring is the lower maximum temperature(228 degrees F) found in the Gulf Land D No.51 as compared to the maximum temperature(298 degrees F) found in the Watkins No.16.

When comparing temperature with depth on the log in the Gulf Land D No.51, the Cam C-1 temperature(190 degrees) is lower than the Cam C-2,3 temperature(228 degrees F). The lower temperature found in the Cam C-1 would seem to indicate that more air has been injected into the Cam C-1 than into the Cam C-2,3 in the Gulf Land D No.51.

4.3.4 Corrosion Problems

On March 27, 1995, the Watkins No.16(air injector) developed pressure communication between the tubing and the tubing/casing annulus. Air injection into the Watkins No.16 was immediately stopped due to concerns regarding corrosion and casing integrity. While the Watkins No.16 was shut in, the entirety of the compressed air stream was injected into the Gulf Land D No.51 until the Gulf Land D No.51 also developed pressure communication between the tubing and the tubing/casing annulus and it was also shut in. The suspected cause of the communication in both air injectors is corrosion resulting from the combination of oxygen or carbon dioxide with KCl purge water. A workover rig was moved on the Gulf Land D No.51 and the tubing was pulled. An examination of the tubing indicated several leaks due to corrosion. The tubing string in the Gulf Land D No.51 was replaced with a new string of coated tubing. As a cost savings measure, the tubing string in the Watkins No.16 will be replaced with the tubing string from the Watkins No.5. During 1991, a nitrogen injection test was run in the Watkins No.5 and new tubing with premium connections was installed at that time. The Watkins No.5 will

GULF LAND D NO.51

CAM C-1,2,3

Schlumberger

DUAL BURST THERMAL
DECAY TIME LOG

COMPANY	AMOCO PRODUCTION COMPANY
WELL	GLD #51
FIELD	WEST HACKBERRY
PARISH	CAMERON	STATE	LOUISIANA

TSCF(CPS)

12000.   0.0

TSCN(CPS)

30000.   0.0

SIGM(CU)

60.000   0.0

7300

1898 psi →

1896 psi →

← 176°F

190°F

1939 psi →

← 218°F

← 228°F

7400

5750cc Oil
16 fts gas
occ water

202°F →   1683 psi →

1673 psi →

▼ ---SIGM

190°F →

25

be temporarily abandoned at this time. By installing coated tubing in the Gulf Land D No.51 and uncoated tubing in the Watkins No.16, a comparison of tubing life for coated versus uncoated tubing during air injection operations will be obtained.

Surface corrosion has also been noted in the valves at the wellsite injection skids. This is believed to be the result of the back pressure valves leaking and allowing KCl water back into the air injection lines. No evidence of corrosion has been found in the equipment immediately downstream of the air compressors. Based upon the experiences of other air injection projects, corrosion from downstream of the air compressors to the wellsite injection skids is not believed to be a significant problem.

After a meeting between corrosion experts, field personnel and the facilities engineer, a consensus was reached that the primary source of corrosion at both the wellsite injection skid and downhole was the combination of KCl purge water with oxygen and or carbon dioxide. The water purge system has served two purposes:
1)The first purpose was to prevent the wellbore from overheating due to the backflow of burning hydrocarbons. With the volume of air injected into the Gulf Land D No.51 and the Watkins No.16 thus far, much of the near-wellbore hydrocarbons appears to have been burned off and purging with KCl water is no longer believed to be necessary.
2) The second purpose for purge water was to prevent explosions resulting from the mixture of oxygen and hydrocarbons in the wellbore. A recent gas analysis of gas flowed back from the Watkins No.16 indicated that the produced gas was 98.3% nitrogen, 1.5% oxygen and a trace of hydrocarbon gasses. The gas flowed back from the Gulf Land D No.51 was 97.4% nitrogen, 2.3% oxygen and a trace of hydrocarbon gasses. The gas mixture flowed back from the air injectors has so little hydrocarbon fraction that the potential for explosion in the tubulars in the air injectors is non-existent.

In the original project design, the water purge system was expected to be in service for a limited time period, six months to a year, until purging was no longer necessary. In June of 1995, the use of the water purge system was discontinued to alleviate corrosion with no apparent negative consequences.

4.3.5 Compressor Mechanical Failures
A table entitled "Causes of Air Injection Downtime" is included on the following page. Some downtime can be attributed to the normal "debugging" associated with a new and complex installation. However, compressor mechanical failures have been a significant cause of air injection downtime. Discussed below are the significant mechanical failures, causes and remedies to date. Most have been covered under warranty by the equipment manufacturers.

Rod packing failures have occurred on the Ariel JGK-4 reciprocating compressor. The failures have occurred on throws 1 and 3 which are the rods for the higher pressure stages 3, 4, and 5. Stages 4 and 5 are a tandem cylinder sharing the same rod and will be referred to only as stage 4 for the remainder of this discussion. Examination of the failed parts indicated heat related failures. New packing cases were designed and installed for stages

CAUSES OF AIR INJECTION DOWNTIME

RECIPROCATING COMPRESSOR

COMPRESSOR ROD PACKING
COMPRESSOR VALVES
COMPRESSOR RINGS AND PISTON 4TH STAGE
HIGH INTERSTAGE DISCHARGE PRESSURES
MAGNETO
TURBOCHARGERS
FAN IDLER BEARING
FUEL VALVE
FUEL SHUTTLE VALVE
ADMISSION VALVES
ANNUNCIATOR POWER SUPPLY
THERMOCOUPLE 4TH STAGE DISCHARGE
WIRING SHORT DUE TO WATER
SCRUBBER HIGH LEVELS
AFTER SCRUBBER DUMP VALVE LEAK
EMISSIONS

SCREW COMPRESSOR

STARTERS
ADMISSION VALVES
OIL COOLER LEAK
MANUAL LOAD VALVE
COMPRESSOR CRANKCASE VENT LOCATION

AMOCO SYSTEM

TUBING/ANNULUS COMMUNICATION IN INJECTION WELLS
DEBUGGING AUTOMATION AND PURGE WATER SYSTEM
MANUMATIC VALVE ON GLD 51
LEAKING CHECK VALVES
PLUGGED CONTROL VALVES

BOLD ITEMS HAVE CAUSED SIGNIFICANT DOWNTIME (GREATER THAN 1 WEEK).

3 and 4. The new packing cases are water cooled for heat dissipation, have two lube points instead of one for better lubricant distribution, have 4 seal ring assemblies instead of 5 to reduce friction, use polymer filled Teflon rings instead of carbon filled Teflon to reduce friction and use bronze back-up rings instead of cast iron for better heat dissipation. This resulted in a rod temperature reduction from 300+ degrees Fahrenheit, which was causing failures, to an acceptable 187 degrees Fahrenheit. The lubricant was also changed from an SAE 40 to a lower viscosity SAE 30 to reduce friction and temperature. When last checked on 8/14/95, the rod temperatures were 201, 203, 181 and 187 degrees on stages 1, 2, 3 and 4, respectively. This appears to have solved the problem and reasonable rod packing life is expected in the future. In future installations, water-cooled packing should be installed for stages where the discharge pressure exceeds 1000 psi.

Compressor valve failures have occurred on the Ariel JGK-4 reciprocating compressor. The failures occurred mostly on stages 3 and 4. The failures have been caused by improper valve springing for actual operating conditions, incorrect valve springs installed by a non-authorized valve service center and excessive heat caused by other mechanical and lubrication failures. New Hoerbiger valves are being installed with the latest recommended springing for actual operating conditions. Future valve repairs will be performed by only Hoerbiger authorized service centers to prevent incorrect springs from being installed.

A mechanical failure occurred to both turbochargers on the Waukesha 9390 GL engine which drives the reciprocating compressor. The failure was caused by insufficient lubrication due to hot shutdowns. This occurs when the turbos, which operate at high temperature and rpm's, continue to spin due to the momentum in the turbine wheel after the engine oil pressure has dropped due to the shutdown. A post lube shut down system has been designed and is presently being installed which should prevent future turbo failures. When the engine shuts down, the prelube pump will automatically come on and lubricate the engine for 3-5 minutes after shutdown. In addition, the engine oil pump will be adjusted from the present setting of 45 psi to 55 psi and the oil pressure shut down switch will be set to 35 psi from its present setting of 25 psi. This post lube system will be tested and debugged on the 9390 and later installed on the 5108 engine driving the screw compressor.

A mechanical failure occurred on the oil cooler of the Atlas Copco ZR-6 screw compressor. The failure was caused by a defective casting end plate allowing communication between the oil and water. The cooler was replaced by Atlas Copco and the failure should be a one time occurrence.

Numerous problems have occurred with the admission valves on both of the Waukesha GL "lean burn" engines. The GL "lean burn" engine achieves its low emissions through use of a pre-chamber where a charge is pre-ignited and forms the flame front ignition source which allows ignition of the lean mixture in the main combustion chamber. The admission valve is the valve that admits gas into the pre-chamber. Waukesha has

modified the admission valve assembly and has provided the new updated admission valves. The field personnel were also provided with the updated service bulletin. In addition, Waukesha has made a service call to the field and has cleaned and inspected the entire fuel system. This should reduce the downtime related to admission valve problems.

Recently a mechanical failure has occurred to the piston and rings on the 4th stage of the reciprocating compressor. The failure appears to be due to lack of lubrication. Ariel is currently machining a new piston and cylinder assembly which will be installed the week of 9/11/95. The new piston design will incorporate a rider band to reduce friction and add piston to cylinder clearance to improve lubrication flow around the piston and rings. The lubrication distribution system is also being modified to improve lubrication to the 4th stage cylinder.

4.3.6 Possible Production Response in Fault Block IV
The recompletions of the Gulf Land D Nos.44(ongoing) and 45(completed) represent an effort to compensate for lower than anticipated air injection volumes by completing wells higher on structure and thereby accelerating production response. In August of 1995, the Gulf Land D No.45 was successfully recompleted downhole from the Marg Howei to the Cam C-1,2 Sand. The Gulf Land D No.45 had previously watered out in December of 1990 in the identical perforation interval in the Cam C-1,2 while producing less than 10 BOPD with greater than a 95% water cut. A production plot for the Gulf Land D No.45 is included on Page No.12. On August 17, 1995, the Gulf Land D No.45 tested gas lifting at a rate of 190 BOPD, 451 BWPD and 25 MSCFD with no evidence of nitrogen production. On the following page is a section of the induction log from the Gulf Land D No.45. The source of the oil production in the Gulf Land D No.45 is either due to response to air injection or due to zones now producing through a gravel pack that had previously sanded up. More production performance will be required to determine the source of the new oil production in the Gulf Land D No.45. The Gulf Land D No.44 is slightly upstructure to the Gulf Land D No.45. If successful, the recompletion of the Gulf Land D No.44 is expected to validate the oil production seen in the Gulf Land D No.45. In order to better relate past production to current production performance, a Cam C-1 structure map on Page No.27 is posted with cumulative production from each Cam C-1 completion.

4.4 Amoco's West Hackberry Reservoir Simulation Activities
By mathematically describing the reservoir characteristics and the controlling process physics, predictions of future reservoir performance under the various operating alternatives are made to assist reservoir management decisions. Moreover, the reservoir model represents one vehicle for transferring technical knowledge of this advanced oil recovery process. As technical understanding improves, predictions of future reservoir performance become more reliable and confidence in applying this recovery process in other reservoirs increases.

Gulf Land
D No. 45

Cam City "33" Sand

07900

08000

SNLG (OHMM)

0.2   20

TEN (LBS)
10000   0

RTLG (OHMM)
0.2   20

SP (MV)
0   150

COND (MMHO)
4000

31

AMOCO

Fault F

FAULT B

Fault Block

FAULT H

Fault Block II

Fault Block III

FAULT A

J. B. Watkins St. FAULT D

Fault Block IV

GULF LAND D R/A A AMOCO

GULF A R/A AMOCO

Fault Block V

FAULT J

J. B. Watkins

FAULT J

NDE (SaH)

UNC

OWC

COWC

Amoco Production Company
HACKBERRY FIELD
STRUCTURE MAP
CAM C-1 SAND
CAMERON PH., LOUISIANA

0'   400'
graphic scale

le # 752 RF= 484   Revised: 12-21-95

Initial West Hackberry reservoir simulations, reported earlier, were conducted with the limited information then available to provide preliminary predictions of field performance under air injection. While these results were suitable for project authorization, subsequent application in predicting the timing of fluid movement within the reservoir has proven to be less than satisfactory. Typically, history matching of reservoir performance is required to resolve uncertain reservoir properties adversely affecting such predictions. History matching of Fault Blocks II and IV will be pursued in the upcoming year.

As discussed below two developments, namely characterization of the West Hackberry reservoir oil and modeling of West Hackberry laboratory combustion tube runs, have been completed and documented during this reporting period. Ultimately, these will lead to improved simulation of the air injection process when merged with the understanding gained from history matching field performance and that derived from current research into the effect of air flux on the in-situ combustion process for light oils. The latter knowledge will create the capability to scale the combustion tube results from laboratory conditions to lower air flux conditions which occur within the reservoir when the combustion front is far away from an injection well.

4.4.1 Characterization of the West Hackberry Reservoir Oil

For use in compositional reservoir simulation work as well as the modeling of laboratory combustion tube tests, a fluid description consistent with measured physical properties and phase behavior was developed for the West Hackberry reservoir oil. The report entitled "Characterization of West Hackberry Oil for Modeling the Air Injection Performance" by M. R. Fassihi documents the methodology followed and the resulting reservoir oil characterization and is included in Appendix B.

Developing the fluid description for the West Hackberry reservoir oil involved grouping the many hydrocarbon species present in the oil into six pseudocomponent fractions. Characterizing parameters were assigned to each of these pseudocomponents so that known properties of the reservoir oil were matched by the fluid property correlations internal to the THERM and STARS reservoir simulation software used in this project. Furthermore, this fluid characterization was tuned to reproduce the vaporization behavior observed in high pressure coreflood displacements of the reservoir oil by flue gas.

4.4.2 Modeling of the West Hackberry Combustion Tube Tests

Under contract to Amoco, Professor John Belgrave of the University of Calgary, a leading authority on combustion tube simulation, completed his efforts to model two Amoco West Hackberry combustion tube runs conducted at the Fault Block II and Fault Block IV reservoir conditions, respectively. Professor Belgrave's work is fully documented in the report entitled "Simulation of the West Hackberry Oil Air Injection Combustion Tube Tests" which is included as Appendix C.

Utilizing the above reservoir fluid characterization, Professor Belgrave tuned global reaction parameters and temperature dependencies of flow properties to match laboratory

combustion tube performance with the STARS compositional thermal reservoir simulator available from the Computer Modeling Group of Calgary. Good agreement with laboratory measurements was obtained with reasonable adjustments well within established uncertainties.

4.5 Technology Transfer Activities

In the area of technology transfer, work has proceeded with Amoco personnel hosting informal field tours of the air injection project. On April 18, 1995, a representative of Kerr-McGee toured the air injection site. On April 27, 1995, four representatives of TOTAL Minatome Corporation toured the air injection project. Both TOTAL and Kerr-McGee are currently evaluating air injection projects in the United States in the Williston Basin(North Dakota, S. Dakota and Montana).

On March 30, 1995, an official start-up ceremony and media event was held at West Hackberry Field for the purpose of publicizing the project. Those attending the ceremony included Gene Pauling(DOE), Tammy Borgoyne(LSU), Dr. Bill Bernard(LSU) and local television, radio and newspaper reporters. The project received favorable news reports concerning the project which appeared on local radio and television stations and in the local newspapers. Excerpts of the news release also appeared in the April 10th edition of "Improved Recovery Week".

On June 20, 1995, an impromptu West Hackberry air injection project presentation was given to members of an air injection consortium in Tulsa, Oklahoma. Representatives from Shell, Kerr-McGee, NIPER, Phillips and Petro-Canada were in attendance.

The technology transfer activities thus far have been an effort to introduce the concept of combining air injection with the double displacement process to the industry. The next round of technology transfer activities will present early operating experiences and evidence of production response.

On September 19, 1995, Amoco will give a short presentation to an oil industry workshop on fluid imaging at the BP Plaza in Houston, Texas. In addition, both Amoco and LSU have submitted abstracts to an improved oil recovery conference scheduled for April 21-24, 1996, in Tulsa, Oklahoma. Amoco's paper will discuss the economic aspects of light oil air injection projects. The LSU paper will review the results of LSU's core tests. As additional operating experience is gained from the project, more technology transfer activities will be planned to share key learnings.

4.6 Independent Project Study by LSU

Three graduate students have been studying the West Hackberry Tertiary Project with the support of three professors. While two of the students have been involved with evaluating screening criteria for such projects and history matching reservoir performance to date, the third graduate student has been performing core floods and filming floods of transparent cells to visualize the process. A report on the core floods entitled "Physical

Modeling of Oil Displacement by Gas in Water-Invaded Zones" is included in Appendix D. One potentially valuable development from the core floods is an observation from that after the cores have undergone some gravity drainage, subsequent flooding with water appears to recover even more oil. This phenomena will be evaluated further during future core floods.

4.7 3-D Seismic Survey

Acquisition of the 60 square mile 3D seismic survey over the north and west flanks of Hackberry field was completed October 30, 1995. A variety of modifications to a basic orthogonal 3-D design were employed in order to image the numerous steeply dipping reservoirs on the flanks of the salt dome. Short line segments were deployed on and near the top of the reservoirs in order to supplement for any shot-skipping necessary due to surface obstructions and to minimize the overall distance between shot and receiver pairs. Receiver line segments were also deployed at the far offsets in order to better sample the expected shape of the reflected wavefront; the entire spread of geophones were laid out for the first six and last three swaths for the same reason. A complete list of acquisition design parameters is included on the following page. Processing will be performed at Amoco and will include state-of-the-art techniques (e.g., static corrections, multiple velocity analyses, 3-D DMO, one-pass 3-D migration). Finally, the dataset, which will be binned at 55 ft. by 55 ft., will be analyzed in the area of the air injection project for amplitude anomalies associated with the building gas cap.

Hackberry 3-D
Acquisition Parameters

Surface Coverage	60 square miles
Receiver Line Spacing	1650'/1870'
Shot Line Spacing	1650'/1870'
Group/Shot Interval	220'
Active Spread	952 to 1500+
Recording Instruments	SGR
Energy Source	Pentolite
Bin Size	55' X 55'
Fold	12
Max Offset	20,000'
Shothole Depth	120'
Charge Size	11 lbs.
# Shotholes	4264

STATEMENT OF WORK

WEST HACKBERRY TERTIARY PROJECT

Amoco Production Company
October 16, 1992

Background and Objectives

The goal of the West Hackberry Tertiary Project is to demonstrate the technical and economic feasibility of oil recovery using air injection in the Double Displacement Process. The Double Displacement Process is the gas displacement of a water invaded oil column for the purpose of recovering oil through gravity drainage. A novel aspect of this project is the use of air as the injection fluid. This technology will be applicable to reservoirs which have both sufficient bed dip for gravity drainage and sufficient reservoir temperature for the consumption of oxygen. Numerous water-drive reservoirs associated with salt dome fields along the Gulf Coast would be potential follow-up candidates for this technology. The use of air injection in this process offer the benefits of air's excellent accessibility and low cost combined with potentially greater recovery due to the combustion process. If successful, this project will demonstrate that the use of air injection in the Double Displacement Process can economically recover oil in reservoirs where tertiary oil recovery is presently uneconomical.

Based on a preliminary project design developed prior to commencement of the project, the following basic operational information has been determined for the study: injection rates; selection of reservoirs and fault blocks; required number of producing and injection wells; requirements for new wells versus re-completing existing wells; requirements for continuous injection versus intermittent injection; assessment of the disposal of produced gases by flaring or injection into low pressure reservoirs; unitization; and the design of surface production and injection facilities. The project is designed for injection into two separate fault blocks (Fault Blocks II & IV). In Fault Block IV, the technology will be assessed using a line of four producers at structurally equivalent positions in a heavily developed area. In Fault Block II, the technology will be assessed using a single producer in a sparsely developed area.

A description of each task associated with the project is provided below.

Task 1 - Environmental Study

It is anticipated that this project will be categorically excluded from the DOE NEPA requirements. Upon DOE certification, if this project does qualify for a categorical exclusion, this task will not be required. If this project does not qualify for a categorical exclusion, then this task will involve activities, such as data collection and reporting, that are required by the DOE to meet NEPA requirements.

Task 2 - Construction of Surface Facilities

The necessary permits required for construction of the surface facilities will be obtained. Based on the preliminary project design, Amoco will acquire the necessary equipment/facilities to inject 4-4.5 MMCFD of air at pressures greater than 4000 psi. Surface injection facilities will be installed which consist primarily of the air compressors and water purge system for the injection wells. The timing for the installation of production facilities will be tied to workovers on the producing wells conducted in Task 5. The production facilities will consist of flowlines, possibly an Natural Gas Liquids recovery unit, and a separate-test-and-boost (STAB) facility. After separation and testing, produced fluids will

be piped to Amoco's central production facility. Undesired produced gasses will be flared or injected into low pressure reservoirs.

Task 3 - Conversion of Producing Wells to Injection Wells

Two producing wells will be converted to injection wells. Initially, a single injection well will be dedicated to each of the two fault blocks. Two additional injectors (i.e. converted producing wells) may be required to improve the economics of the process. A typical workover to convert a producing well to an injector would require cleaning out the wellbore, perforating the full prospective injection interval, and completing the well with new packers, tubing, and wellhead (i.e. valves, etc.).

Task 4 - Operations and Maintenance of Injection Facilities

The operation of the high pressure air compressors in the injection facilities requires close attention to safety issues. Synthetic lubricants and periodic cleaning of injection equipment will be conducted to prevent the possibility of a detonation resulting from the combination of high pressure air and hydrocarbon deposits. Additionally, routine maintenance of injection equipment will be conducted to avoid the possibility of catastrophic mechanical failure. Workovers to repair injection wells will be performed on an as needed basis.

Task 5 - Workovers for Monitoring and Producing Wells

A total of 9 wells will be repaired and/or re-completed to serve as producing wells and/or monitoring wells for the project. The timing of the workovers will be dictated by the advance of the flood front. The task of monitoring the flood front is addressed in Task 6. Once the project is underway, workovers to repair producing and monitoring wells will be performed on an as needed basis.

Task 6 - Production Operations

All production operations for the project will be handled by Amoco field personnel assigned to West Hackberry Field. Produced liquids will be transported through existing collection lines to be handled at an Amoco Tank Battery. Initially, producing wells will be gas lifted within Amoco's field-wide gas lift system. When the produced gasses become concentrated with undesirable components (e.g. nitrogen and carbon dioxide) due to breakthrough, it will be necessary to install a separate gas lift system for the project. The separate gas lift system will require a gas lift compressor. Produced gasses will either be sold, burned as fuel, flared or re-injected into low pressure reservoirs on the north flank of the field. Booster compressors may be required to generate sufficient pressure for injection of produced gasses. A flowline will be installed to the north flank of West Hackberry Field in order to carry the produced gasses to the low pressure reservoirs in that area. Monthly production tests, at a minimum, will be performed on all producing wells. Gas analyses will be conducted periodically to monitor the composition and oxygen content of the produced gasses. Produced oil and water samples will be analyzed periodically to determine their composition and physical properties. Pulsed neutron logs, bottom hole pressure surveys, temperature surveys, and spinner surveys may be run in both producing and monitoring wells in order assess the effectiveness of the project. Periodic replacement of surface production and injection equipment (including flowlines) may also be required due to wear and tear on these items.

Task 7 - Reservoir Management

Reservoir modeling studies will be conducted to effectively manage the project. These studies will assist in assessing the following: distribution of injection volumes; timing of repairs and re-completions; and the determination of monitoring schemes and schedules. Amoco's "THERM" reservoir model will be used to history match reservoir performance and to predict future reservoir performance. Specialized combustion tests will be conducted at Amoco's Combustion Laboratory in Tulsa, Oklahoma to assist in monitoring and predicting the performance of the project. Reservoir fluid property analyses will be conducted to calibrate the reservoir model. The results of reservoir management will be continually documented and reported in a manner consistent with the DOE reporting requirements and technology transfer needs of the project.

Task 8 - Louisiana State University Technology Transfer

A yearly Amoco grant will be provided to the Petroleum Engineering Department at Louisiana State University (LSU). LSU will study various aspects of the project and report their findings. LSU will publish and make industry presentations on all results from their analyses. Amoco plans to provide LSU with all pertinent data and information from the project. Examples of typical data and information that will be made available to LSU include the following: individual well production rates; individual well injection rates; structure maps; net pay isopachs; core data; well logs; gas analyses; and fluid property data.

Task 9 - Amoco Technology Transfer

Amoco will assess the technical and economic feasibility of Double Displacement Process based on the data and information acquired from the project. These results will be documented and submitted to various technical conferences for presentation and/or publication. Since the Double Displacement Process will probably have its greatest applicability to salt dome fields along the Gulf Coast, Amoco personnel will focus on technical conferences in the Houston, Texas and New Orleans, Louisiana areas. It is anticipated that presentations and/or papers will be completed at the beginning, middle, and end of the project. Amoco does not intend to regard any data and/or information on this project as proprietary.

Characterization of West Hackberry Oil for Modeling the Air Injection Performance

M. R. Fassihi   *January 13, 1995*

Executive Summary

Background

Amoco, in partnership with U.S. Department of Energy, initiated during 1994 an air injection project in the West Hackberry field, located in Southwest Louisiana. The combination of thermal displacement and gravity drainage are the main driving forces for this oil recovery project. Air will be injected into two fault blocks with existing pressures of 2000 psi and 3500 psi respectively.

Purpose

To aid in the evaluation of the project performance, a numerical simulator will be used to model the process in this reservoir. The simulator requires detailed information on the properties of all fluids involved in the process, including combustion flue gas and reservoir oil. The results of two flue gas coreflood tests conducted at Amoco's E&PTG-Tulsa have been documented in a report and were distributed previously (Hackberry Field Characterization Tests, 941090011-APR, March 30, 1994). These results were used to tune the equation-of-state (EOS) parameters to describe the West Hackberry oil. An EOS optimization routine was used for this purpose; then GCOMP was used to history match the corefloods. The simulation results were used to arrive at the corresponding component K-values. The latter are needed for Amoco's in-house thermal model, THERM. This model will be used to simulate the combustion tube tests and the field performance.

Conclusions in Brief

Once the EOS parameters were optimized, a good history match was obtained for the two laboratory corefloods.

The component K-values that were extracted from the model results were used to study the compositional effects. The K-values displayed a unique correlating behavior with respect to the mole fraction of nitrogen in the oil phase (X_{N_2}).

Discussion of Principal Conclusions

The correlation of component K-values versus X_{N_2} can be used in a numerical thermal model to account for the compositional dependency of different components. Such effects are very important for the light oil systems. Also, the good match between the laboratory corefloods and simulation results indicates that the fluids are characterized adequately.

Significance

All of the fluid properties needed to model the combustion tube tests were generated in this work.

Recommendations

The results of this work should be used in THERM (or the Computer Modeling Group's STARS) model to:

1. Test the K-values (by matching the flue gas corefloods),
2. Model the combustion tube tests.

Procedure for Fluid Characterization

The flowchart in Figure 1 illustrates the procedure used to characterize the West Hackberry oil-flue gas behavior. The laboratory measured PVT and oil-flue gas mixture data (see Ref. 1) were used in an EOS optimization program to tune the EOS parameters for an eight-component and a ten-component description (see Appendix A for details).
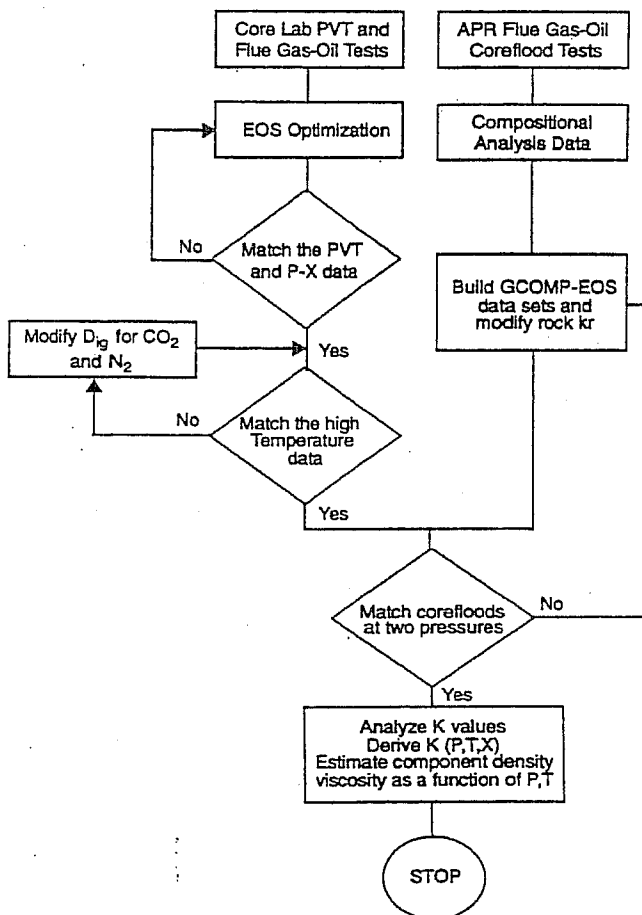
Figure 1. Procedure for fluid characterization.

As shown in Figures 2-6, the EOS descriptions provided a good match of the laboratory data. Next, a six-component data set was built to history match the coreflood tests (Ref. 1). The gravity override in those horizontal tests made the task somewhat difficult. A multilayer simulation could not be obtained because of a·very small pressure drop between those layers (the GCOMP solution did not converge, even though it was run on a Cray with good precision). Thus, the relative permeability had to be adjusted to match the gas breakthrough time (see Appendix B). A comparison between the oil recovery in two coreflood tests and the GCOMP match is provided in Figure 8. The compositional profiles in those tests and the corresponding simulation results are provided in Figures 9-11. As shown, the agreement is good at both pressure levels of 2200 and 3500 psi.
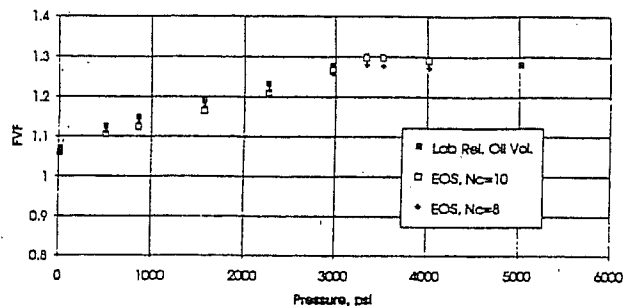
Figure 2. Oil Formation Volume Factor.
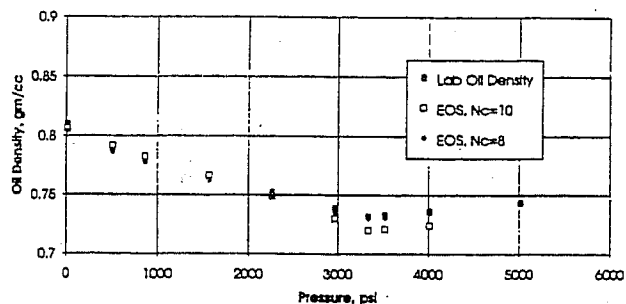
Figure 3. Oil Density.
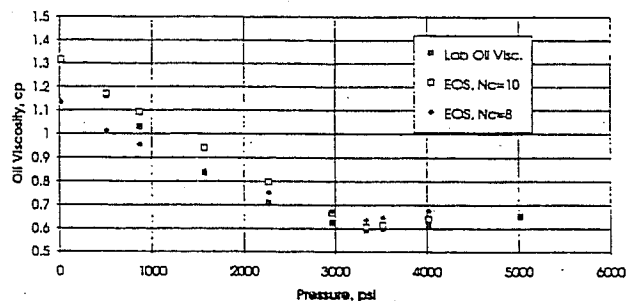
Figure 4. Oil Viscosity.
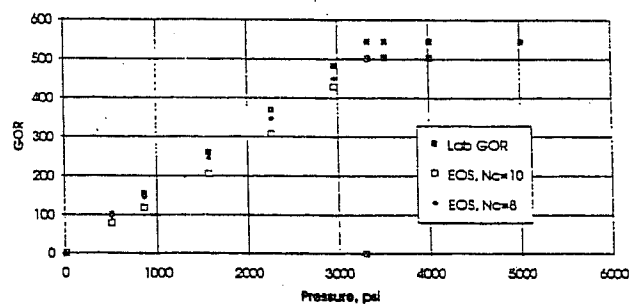
Figure 5. Solution Gas-Oil Ratio.

Estimation of K-Values

From simulation results at 3500 psi, K-values of different components were extracted at 25%, 75% and 1 HCPVI. These K-values were cross-correlated against the mole fraction of nitrogen in the oil phase X_{N_2} and are shown in Figures 13-15. For the most part, the correlation exhibits a straight line. The following equation was fitted to these curves:

Figure 6.   Saturation Pressure for Oil-Flue Gas Mixture.

Figure 7.   Swelling Factor for Oil-Flue Gas Mixture.
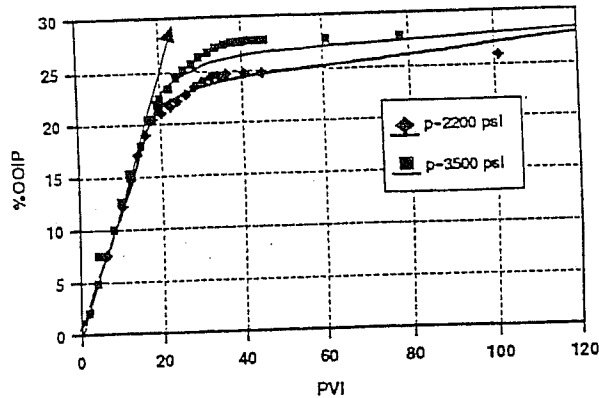
Figure 8. Oil Recovery in the Flue Gas Corefloods (Points) and Simulation Results (Solid Lines).

Figure 11. Gas Effluent Composition at 2200 psi, Lab Results (Points) and Simulation (Solid Lines).

Figure 9. Gas Effluent Composition at 3500 psi, Lab Results (Points) and Simulation (Solid Lines).
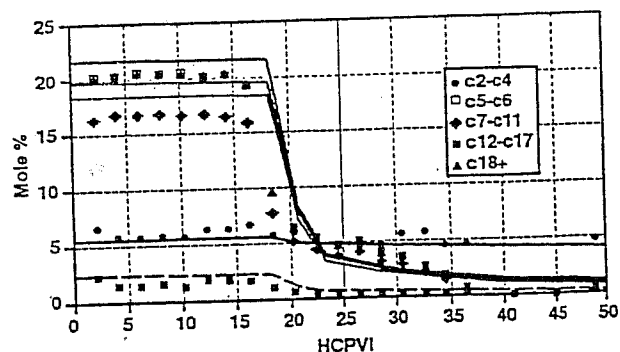
Figure 12. Effluent Composition at 2200 psi, Lab Results (Points) and Simulation (Lines).

Figure 10. Effluent Composition at 3500 psi, Lab Results (Points) and Simulation (Lines).

$$\frac{\log KV\,(X_{N_2})}{\log KV\,(X_{N_2}=0)} = a + bX_{N_2}$$

These coefficients are provided in Table 1. The K-values at zero X_{N_2} and at two different temperatures and pressures are also shown in this table.
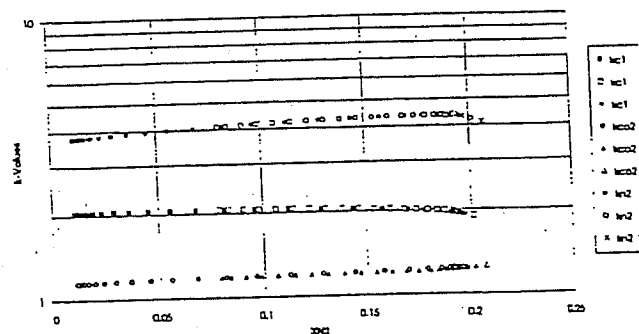
Figure 13. K-Values at 3500 psi (C_1, CO_2, N_2).
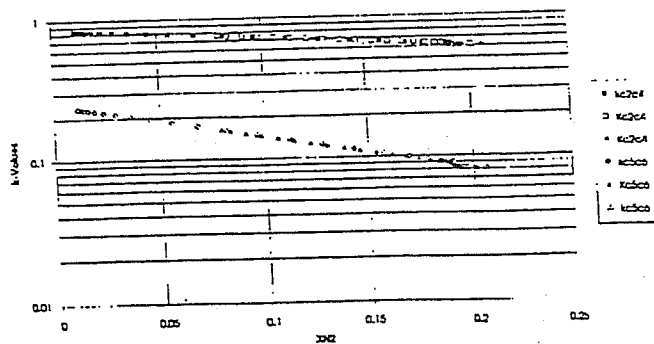
Figure 14. K-Values at 3500 psi (C_2-C_4, C_5-C_6).
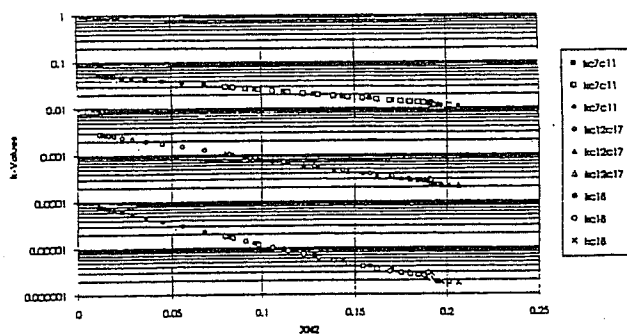
Figure 15. K-Values at 3500 psi (C_7-C_{11}, C_{12}-C_{17}, C_{18}+).

Other component properties such as molecular weight, critical temperature and pressures, etc., are provided in Table 3.

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Table 1: K-Values at Different Pressure and Temperatures, West Hackberry - (ARKES Results of 1-D Run)

Comp. Name	K-Value at 2000 psia		K-Value at 3000 psia		Log k/log k (xn2=0)=a+b(xn2)	
	200°F	400°F	200°F	400°F	a	b
N_2	6.26	4.992	4.326	3.5	1	0.7425
C_1	.2.922	2.985	2.237	2.225	1	0
CO_2	1.532	1.572	1.225	1.238	1	3.9829
C_2-C_4	0.8823	1.337	0.8398	1.121	1	14.8236
C_5-C_6	0.1557	0.4357	0.2059	0.4369	1	3.9086
C_7-C_{11}	2.30E-02	0.1308	4.06E-02	0.1538	1	3.0547
C_{12}-C_{17}	4.42E-04	8.76E-03	1.64E-03	1.58E-02	1	2.5149
C_{18}+	2.40E-06	2.51E-04	2.81E-05	8.50E-04	1	2.1871

Estimation of Flow Properties

The viscosity and density of different components were extracted from the ARKES description using PVTCALC. These are exhibited in Table 2.

Table 2: Viscosity and Density of HC Components at Different Temperatures

No.		Oil Phase @ T, °F		Gas Phase @ T, °F	
1	C_{18}+	17.4568	200	0.023	280°F
		5.2398	400	0.07	400°F
2	N_2	.2235	200	0.165	280°F
		.11	400	0.362	400°F
3	C_1	.2213	400	.0362	400°F
		.11	200	.0257	280°F
4	CO_2	.0489	200	.0245	280°F
		.0324	400	.0486	400°F
5	C_2-C_4	.0565	200	.0245	280°F
		.0363	400	.0488	400°F
6	C_5-C_6	.1836	200	.0245	280°F
		.09	400	.0488	400°F
7	C_7-C_{11}	.6698	200	.0245	280°F
		.2858	400	.0488	400°F
8	C_{12}-C_{17}	1.5508	200	.0245	280°F
		.6067	400	.0488	400°F

$$\mu_{oil} = \prod_i \mu_i^{x_i}$$

Density of different components @ standard conditions.

Comp. No.	1	5	6	7	8
Density, lb/ft^3	56.02	27.87	40.46	49.66	53.46

Table 3: Other Component Properties

	N_2	C_1	CO_2	C_2-C_4	C_5-C_8	C_7-C_{11}	C_{12}-C_{17}	C_{18+}
MW	28.01	16.04	44.01	39.62	79.99	112.51	190.56	358.96
T_c, °R	227.2	343.	5476	622.8	875.2	1080.4	1399.4	1633.0
P_c, psia	493.1	666.4	1070.7	649.3	460.3	440.2	287.9	156.1
ρ, g/cc @ 3500 psi & 200°F	.1989 (ρ_l = .8086)	.1324	.5921(ρ_l = .8172)	.4142	.6183	.7946	.8518	.9580
ρ, g/cc @ 400°F	.1515	.0937	.3116	.2933	.5282	.7187	.7816	.886
Oil phase @ 3500 psi (x_{oil}), %	1.03	42.76	.48	5.39	1.95	15.9188	14.8904	17.0

Resid oil density @ 60°F (DVA) = .8617 [Core Lab = .8664]
Resid oil viscosity @ 201°F = 1.238 [Core Lab = 1.55]
MW_{oil} = 121.4 @ p = 3500 psi and T = 201°F
ρ_o = 45.63, μ_o = .6456
ρ_g = 9.996, μ_g = .0215
Oil Compressibility C_o = 1.1 x 10^{-5} 1/psi
Oil thermal expansion coefficient C_T = 3.8E-4 1/°F

Table A-1: West Hackberry Original Description (Nonoptimized)

Appendices for "Characterization of West Hackberry Oil for Modeling the Air Injection Performance"

by

M. R. Fassihi

Appendix A - EOS Optimization

The laboratory PVT data were used as input for the EOS automatic optimization program (developed by J. Mansoori). First, the initial ARKES description (Table A-1) was used to arrive at two new descriptions with lumped pseudocomponents: (1) a 10-component description, (2) an 8-component description (see Table 2 for component description). The appropriate input data sets for the EOS optimization program are shown in Tables A-3 and A-4, respectively. The final EOS parameters are provided in Tables A-5 and A-6. A comparison between the laboratory measured black oil properties (FVF, GOR, density and viscosity) and the EOS dervied PVT data (after optimization) is provided in Figures 1-4. As expected, the description with more components provided a better match.

The properties of EOS derived flue gas-oil mixtures (P-x and drilling factor) are compared with the laboratory data in Figures 5-6. The EOS optimization program did an excellent job of matching these properties. In ordert to match the data at 400°F, the interaction coefficients between CO_2-HC and N_2-HC components had to be manually modified to show the decrease in the saturation pressure with temperature increase. A comparison in the estimated bubblepoint pressure between the original description and the optimized ARKES description is provided in Table A7.

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

Reservoir Fluid Properties at Reservoir Conditions

Feed: Reservoir Oil (STAB 11,12, 13, 14)

Temperature = 201.000 F

			Reservoir Oil Phase			Evolved Solution Gas			
P	FVFO	GORS	DENO	VISO1	VISO2	SPGG	VISG	Z	FVFG
5014.70	1.2317	507.691	0.7615	1.010	0.898				
5000.00	1.2318	507.691	0.7614	1.010	0.897				
4750.00	1.2333	507.691	0.7605	0.996	0.884				
4500.00	1.2351	507.691	0.7594	0.983	0.872				
4250.00	1.2371	507.691	0.7581	0.969	0.859				
4000.00	1.2394	507.691	0.7568	0.955	0.847				
3750.00	1.2419	507.691	0.7552	0.942	0.835				
3500.00	1.2448	507.691	0.7535	0.928	0.822				
3250.00	1.2482	507.691	0.7514	0.914	0.810				
3000.00	1.2521	507.691	0.7491	0.901	0.797				
PP 2920.30	1.2535	507.691	0.7482	0.896	0.793	0.6432	0.0195	0.9145	1.0420
2750.00	1.2407	474.071	0.7522	0.931	0.827	0.6403	0.0189	0.9111	1.1025
2500.00	1.2226	426.074	0.7578	0.982	0.880	0.6364	0.0180	0.9081	1.2087
2250.00	1.2055	379.612	0.7633	1.032	0.940	0.6331	0.0172	0.9072	1.3417
2000.00	1.1891	334.556	0.7686	1.082	1.007	0.6304	0.0165	0.9086	1.5118
1750.00	1.1734	290.798	0.7738	1.130	1.083	0.6285	0.0158	0.9123	1.7347
1500.00	1.1584	248.243	0.7788	1.176	1.170	0.6277	0.0152	0.9181	2.0367
1250.00	1.1439	206.807	0.7837	1.220	1.270	0.6285	0.0147	0.9259	2.4650
1000.00	1.1300	166.401	0.7885	1.260	1.387	0.6318	0.0143	0.9358	3.1139
750.00	1.1164	126.894	0.7931	1.296	1.527	0.6399	0.0139	0.9474	4.2036
500.00	1.1029	87.995	0.7977	1.326	1.697	0.6585	0.0136	0.9608	6.3942
250.00	1.0888	48.587	0.8025	1.352	1.917	0.7133	0.0132	0.9759	12.9894
150.00	1.0826	32.319	0.8045	1.362	2.026	0.7823	0.0130	0.9823	21.7912
100.00	1.0791	23.661	0.8056	1.367	2.090	0.8630	0.0127	0.9855	32.7945
50.00	1.0741	13.106	0.8071	1.376	2.173	1.0690	0.0124	0.9889	65.8114
25.00	1.0696	5.409	0.8083	1.386	2.239	1.4017	0.0117	0.9905	131.8390
14.70	1.0658	0.0	0.8092	1.397	2.287	1.7676	0.0109	0.9912	224.4485

--- DVA residual oil properties ---
Specific gravity (60.F/60.F) = 0.8633
API gravity   =   32.41
Molecular weight   = 220.65

PP   = Bubble point pressure, psia
     = Pressure, psia
VFO = Oil Formation Volume Factor, bbl/bbl
ORS = Gas-Oil Ratio, scf/bbl
ENO = Oil density, g/cc
ISO1 = Oil viscosity, cp (Thodos)
ISO2 = Oil viscosity, cp (Bergman)
PGG = Gas specific gravity, Air=1.0
ISG = Gas viscosity, cp
     = Gas compressibility factor
VFG = Gas formation volume factor, bbl/Mscf

PVTCALC 5.0

Standard conditions for FVFO, GORS, and FVFG are 60.0 F and 14.696 psia

Phase equilibria via Amoco Redlich-Kwong Equation of State (ARKES)
Hall-Yarborough used for Gas Z factor
Standing-Katz used for Liquid density
FVFO & DENO above BPP computed from BPP values using Vasquez-Beggs correlation

Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

Reservoir Fluid Properties at Reservoir Conditions

Feed: Reservoir Oil (STAB 11,12, 13, 14)

Bubble Point pressure at 201.000 F is 2920.304 psia

Component	Feed	Liquid	Vapor	K value
Nitrogen	1.0300	1.0300	4.2275	4.104E+00
Methane	42.7600	42.7600	89.9187	2.103E+00
Carbon dioxide	0.4800	0.4800	0.4855	1.011E+00
Ethane	2.9800	2.9800	2.9365	9.854E-01
Hydrogen sulfide	0.0	0.0	0.0	
Propane	1.1500	1.1500	0.6814	5.925E-01
i-Butane	0.3400	0.3400	0.1440	4.235E-01
n-Butane	0.9200	0.9200	0.3241	3.523E-01
i-Pentane	0.4700	0.4700	0.1223	2.603E-01
n-Pentane	0.3900	0.3900	0.0883	2.265E-01
Hexanes	1.0900	1.0900	0.1763	1.617E-01
C7s	3.1223	3.1223	0.3027	9.696E-02
C8s	3.5293	3.5293	0.2228	6.314E-02
C9s	3.2220	3.2220	0.1324	4.110E-02
C10s	3.1882	3.1882	0.0871	2.733E-02
C11s	2.8570	2.8570	0.0526	1.841E-02
C12s	2.6589	2.6589	0.0333	1.251E-02
C13s	3.0489	3.0489	0.0246	8.081E-03
C14s	2.6502	2.6502	0.0147	5.563E-03
C15s	2.5456	2.5456	0.0098	3.860E-03
C16s - C17s	3.9870	3.9870	0.0092	2.297E-03
C18s - C20s	4.3527	4.3527	0.0044	1.007E-03
C21s - C24s	3.4945	3.4945	0.0012	3.356E-04
C25s - C29s	2.8507	2.8507	0.0002	8.565E-05
C30s+	6.8829	6.8829	0.0002	3.438E-05
Total	100.0000	100.0000	100.0000	

	Feed	Liquid	Vapor	
Mole percent		100.0000	0.0	
Volume percent		100.0000	0.0	
Z factor	1.0705	1.0705	0.9145	
P/Z, psia			3193.4554	
Gas volume factor, bbl/Mscf			1.0420	
Molar volume, cf/lb mol	2.5991	2.5991	2.2202	
Density, g/cc	0.7482	0.7482	0.1344	
Molecular weight	121.4037	121.4037	18.6292	
Gas gravity, Air=1.0			0.6432	
Pseudocritical temperature, R	827.1691	827.1691	357.8266	
Pseudocritical pressure, psia	481.5711	481.5711	658.6683	
Pseudocritical volume, cf/lb mol	8.0554	8.0554	1.6877	
Viscosity (Thodos), cp		0.8964	0.0195	

Phase equilibria via Amoco Redlich-Kwong Equation of State (ARKES)
Hall-Yarborough used for Gas Z factor

Standing-Katz used for Liquid density

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

Reservoir Fluid Properties at Reservoir Conditions

Component Properties of Feed Stream
Table 1

Component	ID	Mole Weight	Critical Temp R	Critical Pressure psia	Acentric Factor
Nitrogen	1	28.01	227.2	493.1	0.0372
Methane	2	16.04	343.0	666.5	0.0105
Carbon dioxide	3	44.01	547.6	1070.7	0.2310
Ethane	4	30.07	549.6	706.5	0.0992
Hydrogen sulfide	5	34.08	672.4	1306.2	0.0911
Propane	6	44.10	665.7	616.0	0.1523
i-Butane	7	58.12	734.1	527.9	0.1852
n-Butane	8	58.12	765.3	550.6	0.1996
i-Pentane	9	72.15	828.7	483.0	0.2223
n-Pentane	10	72.15	845.2	489.5	0.2539
Hexanes	38	86.18	906.0	440.0	0.2867
C7s	256	92.91	985.5	528.2	0.2689
C8s	257	105.63	1039.5	479.9	0.3127
C9s	258	118.36	1088.9	436.7	0.3542
C10s	259	132.38	1131.2	392.4	0.3989
C11s	260	147.06	1168.4	352.6	0.4449
C12s	261	161.74	1202.5	319.6	0.4892
C13s	262	171.19	1248.7	335.5	0.4952
C14s	263	185.88	1277.1	306.6	0.5360
C15s	264	200.53	1303.4	281.9	0.5751
C16s - C17s	265	221.34	1339.4	253.2	0.6268
C18s - C20s	266	255.71	1391.6	215.7	0.7068
C21s - C24s	267	303.99	1454.6	177.6	0.8100
C25s - C29s	268	366.62	1522.9	142.6	0.9348
C30s+	269	449.00	1563.6	124.1	1.0191

Heavy ends characterized by NTYPE characterization method using molecular weight of 228.0 and specific gravity of 0.8685.

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

Reservoir Fluid Properties at Reservoir Conditions

Component Properties of Feed Stream
Table 2

Component	Omega a	Omega b	Critical Volume cf/lb mol	Density @ 60F g/cc	Boiling Point F
Nitrogen	0.397549	0.094559	1.43	--	-320.5
Methane	0.446248	0.089117	1.58	--	-258.7
Carbon dioxide	0.399970	0.081033	1.51	--	-109.3
Ethane	0.414289	0.082685	2.36	--	-127.5
Hydrogen sulfide	0.402213	0.079445	1.56	--	-76.5
Propane	0.402270	0.078970	3.20	--	-43.8
i-Butane	0.410151	0.078645	4.15	--	10.8
n-Butane	0.414596	0.078822	4.09	--	31.1
i-Pentane	0.427206	0.080396	4.90	0.6242	82.1
n-Pentane	0.430267	0.079887	4.87	0.6306	96.9
Hexanes	0.437790	0.079458	5.90	0.6627	148.4
C7s	0.441951	0.080091	5.67	0.7640	188.9
C8s	0.448156	0.078801	6.44	0.7840	238.5
C9s	0.453540	0.077382	7.22	0.8010	284.8
C10s	0.458199	0.075803	8.15	0.8080	328.5
C11s	0.462277	0.074136	9.17	0.8109	369.5
C12s	0.465606	0.072468	10.20	0.8137	407.8
C13s	0.466811	0.072011	10.38	0.8648	442.4
C14s	0.469227	0.070439	11.43	0.8632	476.1
C15s	0.471196	0.068909	12.47	0.8629	507.7
C16s - C17s	0.473345	0.066859	13.94	0.8657	550.2
C18s - C20s	0.475423	0.063671	16.36	0.8718	613.5
C21s - C24s	0.475010	0.059579	19.76	0.8830	691.5
C25s - C29s	0.470087	0.054730	24.15	0.8998	779.1
C30s+	0.464071	0.051585	30.18	0.9114	833.5

ARKES parameters via Yarborough-Morris-Turek correlation (1984).
Omega a and omega b are ARKES parameters evaluated at 201.00 F.

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

Reservoir Fluid Properties at Reservoir Conditions

ARKES Binary Interaction Parameters of Feed Stream

i	j	Cij	i	j	Cij	i	j	Cij	i	j	Cij
1	2	0.028000	1	3	-0.055000	1	4	0.061000	1	5	0.198500
1	6	0.107000	1	7	0.120000	1	8	0.128000	1	9	0.143000
1	10	0.160000	1	38	0.181628	1	256	0.187564	1	257	0.172922
1	258	0.159057	1	259	0.144097	1	260	0.128735	1	261	0.113906
1	262	0.111918	1	263	0.098274	1	264	0.085181	1	265	0.067908
1	266	0.041132	1	267	0.006642	2	3	0.206984	2	4	0.005000
2	5	0.084700	2	6	0.010000	2	7	0.010000	2	8	0.010000
2	9	0.010000	2	10	0.010000	2	38	-0.008000	2	256	-0.008000
2	257	-0.008000	2	258	-0.008000	2	259	-0.008000	2	260	-0.008000
2	261	-0.008000	2	262	-0.008000	2	263	-0.008000	2	264	-0.008000
2	265	-0.008000	2	266	-0.008000	2	267	-0.008000	2	268	-0.008000
2	269	-0.008000	3	4	0.190287	3	5	0.107600	3	6	0.180283
3	7	0.174089	3	8	0.171378	3	9	0.167105	3	10	0.161156
3	38	0.154981	3	256	0.158323	3	257	0.150080	3	258	0.142274
3	259	0.133852	3	260	0.125203	3	261	0.116855	3	262	0.115736
3	263	0.108055	3	264	0.100683	3	265	0.090959	3	266	0.075885
3	267	0.056468	3	268	0.032963	3	269	0.017099	4	5	0.090500
5	6	0.084600	5	7	0.082000	5	8	0.080000	5	9	0.078000
5	10	0.075000	5	38	0.071864	5	256	0.073544	5	257	0.069400
5	258	0.065475	5	259	0.061241	5	260	0.056893	5	261	0.052696
5	262	0.052133	5	263	0.048271	5	264	0.044565	5	265	0.039676
5	266	0.032098	5	267	0.022335						

i	j	Dij	i	j	Dij	i	j	Dij	i	j	Dij
2	3	-0.013491	3	4	-0.013967	3	6	-0.014253	3	7	-0.014429
3	8	-0.014506	3	9	-0.014628	3	10	-0.014798	3	38	-0.014974
3	256	-0.014879	3	257	-0.015114	3	258	-0.015336	3	259	-0.015576
3	260	-0.015823	3	261	-0.016061	3	262	-0.016093	3	263	-0.016312
3	264	-0.016522	3	265	-0.016799	3	266	-0.017229	3	267	-0.017783
3	268	-0.018453	3	269	-0.018906						

Only non-zero binary interaction parameters used in the ARKES are shown.
Component IDs correspond to those in Component Properties Table 1 above.
Binary interaction parameters are evaluated at 201.00 F.

Table A-2: Component Lumping

	5 Pseudo Component		Compsition
(2) 3 Pseudo for $C_{7}+$ (Total 8 Comp.)			
1	N_2		1.03
2	C_1		42.76
3	CO_2		.48
4	PS1	$C_2\text{-}C_4$	5.39
5	PS2	$C_5\text{-}C_6$	1.95
6	PS3	$C_{7\text{-}11}$	15.919
7	PS4	$C_{12\text{-}17}$	14.89
8	PS5	$C_{18\text{-}30}+$	17.581

(1) 4 Pseudo for $C_{7}+$ (Total 10 Comp.)			
1		N_2	1.03
2		C_1	42.76
3		CO_2	.48
4		C_2	2.98
5	PS1	$C_{3\text{-}4}$	2.41
6	PS2	$C_{5\text{-}6}$	1.95
7	PS3	$C_{7\text{-}10}$	13.0617
8	PS4	$C_{11\text{-}15}$	13.7605
9	PS5	$C_{16\text{-}21}$	9.3789
10	PS6	$C_{22}+$	12.1889

Table A-3: Data Sets for Optimizing EOS Parameters for 8 Comp. Description

```
            INITIAL KLAATU FILE
1   11    -4>>>>>(15%CO2&85%N2)-WEST HACKBERRY UNIT SYSTEM<<<<<
8    1    0     0     0    0    1    0    1 1.000E-10   0.00
5    1    0     0     0    1                CONCENTRATION = 0.00000E+00
2 3115.000    201.000   3115.000        .000     201.00     0.000     0    PF
*    1  201 0.0000000 0.0000000 1.0000000
  4  4  4  4  4  4  4  4  1  1  1
3N2      C1       CO2     P1       P2       P3      P4       P5      N2      C1       CO2
   39.620   649.300   622.800  0.446500  0.133100  163.930    2.95
   80.      460.300   875.200  0.648100  0.264600  148.331    5.45
  118.510   440.200  1080.400  0.795400  0.353500  122.377    7.28
  190.560   296.400  1279.200  0.856300  0.550300  122.377   11.84
  358.96    160.700  1492.800  0.897400  0.886600  122.377   23.71
    1    2  0.028000    1    3 -0.055000    1    4  0.000000    1    5  0.189012
    1    6  0.159284    1    7  0.093490    1    8 -0.018966    2    3  0.206984
    2    4  0.000000    2    5  0.010000    2    6  0.010000    2    7  0.010000
    2    8  0.010000    3    4  0.183903    3    5  0.151938    3    6  0.142402
    3    7  0.105361    3    8  0.042051    4    5  0.000000    4    6  0.000000
    4    7  0.000000    4    8  0.000000    5    6  0.000000    5    7  0.000000
    5    8  0.000000    6    7  0.000000    6    8  0.000000    7    8  0.000000


7
    1    2  0.000000    1    3  0.000000    1    4  0.000000    1    5  0.000000
    1    6  0.000000    1    7  0.000000    1    8  0.000000    2    3 -0.013491
    2    4  0.000000    2    5  0.000000    2    6  0.000000    2    7  0.000000
    2    8  0.000000    3    4 -0.014149    3    5 -0.014855    3    6 -0.015333
    3    7 -0.016389    3    8 -0.018194    4    5  0.000000    4    6  0.000000
    4    7  0.000000    4    8  0.000000    5    6  0.000000    5    7  0.000000
    5    8  0.000000    6    7  0.000000    6    8  0.000000    7    8  0.000000

1.0103000   0.4276000  0.0048000  0.0539000  0.0195000  0.1591900  0.1489000  0.1758100
  0.8500000 0.0000000  0.1500000

4
3
****************************
COM
           1           8           3
  1       .0103             0.85
  2       0.4276            0.
  3       0.0048            0.15
  4       0.0539
  5       0.0195
  6       0.1592
  7       0.1489
  8       0.1758
 DVA
           PIN         14           1           5
     4015.
     3515.
     3331.
     2965.
     2615.
     2265.
     1915.
     1565.
     1215.
      865.
      515.
      203.
       15.
```

```
           15.        60.
      BPP
                   3331.          10.     2.     P
        FVF         1
                   1.302          .01     1.     P
         GOR        1
                    545.           5.     1.     P
          ODN       5
                    .7317          .01     .2     P
     4015.          .7372          .01     .2     -
     1565.          .7666          .01     .2     -
      515.          .7890          .01     .2     -
       15.          .8099          .01     .2     -
          OVC       5
                    .594           .01     .2     P
     4015.          .617           .01     .2     -
     1565.          .836           .01     .2     -
      515.         1.16            .01     .2     -
       15.         1.55            .01     .2     -
SAP          3
             1       .05            2
          SPP      4218.          10.      .5     P
          SOD       .7304          .01      .5     P
             1       .10            2
          SPP      5222.          10.      .5     P
          SOD       .7329          .01      .5     P
             1       .20            2
          SPP      7590.          10.      .5     P
          SOD       .7416          .01      .5     P
FLA          1
             1       .08          4015.     5
          VOL       .9354          .01     1.      P
          KVA                              5
             1     3.3914          .05      .3     P
             2     1.987           .05      .3     -
             3     1.2293          .05      .3     -
             4      .655           .05      .1     -
             5      .1756          .05     0.      -
          FOD
                    .7826          .01     1.      -
          FGD
                    .4034          .01     0.      -
          VIL
                    .645           .01     1.      -
SFA          1
             1                      3
           .05     1.0149          .005     .3     P
           .1      1.0261          .005     .3     P
           .2      1.0485          .005     .3     P
PAR
10           8      13             22              29
 1          PC       3       10    11      12
 2          TC       3       10    11      12
 3          WC       3       10    11      12
 4          VC       2        9    10
 5          CIJ      4        1     6
                              1     7
                              2     6
                              2     7
 6          CIJ      2        1     8
```

```
                           2      8
 7      CIJ          1      3      8
 8      DIJ .        4      1      6
                            1      7
                            2      6
                            2      7
 9      DIJ          2      1      8
                            2      8
10      DIJ          1      3      8
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
SOL        1
SIM        1
.05 .05 .05 .05 .05 .05 .05 .05 .05 .05
 .5 .5 .5  .5 .2  .2   .2   .2   .2   .2
-.5 -.5 -.5 -.5 -.2  -.2 -.2 -.2 -.2 -.2
300
```

Table A-4: Data Set for Optimizing EOS Parameters for 10 Comp. Description

```
COM
           1            10            3
  1          .0103         0.85
  2         0.4276         0.
  3         0.0048         0.15
  4         0.0298
  5         0.0241
  6         0.0195
  7         0.1306
  8         0.1376
  9         0.0938
 10         0.1219
DVA
          PIN         14            1            5
     4015.
     3515.
     3331.
     2965.
     2615.
     2265.
     1915.
     1565.
     1215.
      865.
      515.
      203.
       15.
       15.          60.
          BPP
                    3331.          10.     1.      P
          FVF         1
                    1.302          .01     1.      P
          GOR         1
                     545.           5.     2.      P
          ODN         5
                     .7317          .01     .2      P
     4015.          .7372          .01     .2      -
     1565.          .7666          .01     .2      -
      515.          .7890          .01     .2      -
       15.          .8099          .01     .2      -
          OVC         5
                     .594           .01     .2      P
     4015.          .617           .01     .2      -
     1565.          .836           .01     .2      -
      515.         1.16            .01     .2      -
       15.         1.55            .01     .2      -
SAP         3
            1          .05            2
          SPP      4218.          10.      .3      P
          SOD       .7304          .01      .3      P
            1          .10            2
          SPP      5222.          10.      .3      P
          SOD       .7329          .01      .3      P
            1          .20            2
          SPP      7590.          10.      .3      P
          SOD       .7416          .01      .3      P
   FLA         1
            1          .08         4015.     5
          VOL       .9354          .01     1.      P
          KVA                                7
```

```
                    1      3.3914           .05      .5      P
                    2      1.987            .05      .5      -
                    3      1.2293           .05      .5      -
                    4       .8375           .05      .2      -
                    5       .448            .05      .2      -
                    6       .1756           .05      0.      -
                    7       .0472           .05      0.      -
                  FOD
                           .7826           .01      1.      -
                  FGD
                           .4034           .01      0.      -
                  VIL
                           .645            .01      1.      -
    SFA           1
                  1                          3
                  .05    1.0149            .005     .3      P
                  .1     1.0261            .005     .3      P
                  .2     1.0485            .005     .3      P
    PAR
    10            9        15              28              39
     1            PC       4         11    12      13      14
     2            TC       4         11    12      13      14
     3            WC       4         11    12      13      14
     4            VC       2         11    12
     5            CIJ      6         1     7
                                     1     8
                                     1     9
                                     2     7
                                     2     8
                                     2     9
     6            CIJ      2         1     10
                                     2     10
     7            CIJ      1         3     10
     8            DIJ      6         1     7
                                     1     8
                                     1     9
                                     2     7
                                     2     8
                                     2     9
     9            DIJ      2         1     10
                                     2     10
    10            DIJ      1         3     10
    0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
    SOL           1
    SIM           1
    .05 .05 .05 .05 .05 .05 .05 .05 .05 .05
     .5 .5 .5   .5 .2  .2   .2   .2   .2   .2
    -.5 -.5 -.5 -.5 -.2  -.2 -.2 -.2 -.2 -.2
    300
```

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Table A-5: West Hackberry 8 Comp. Description (Optimized)

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

DVA for 5 pseudos

Feed: 3 pseudos for c7+

Temperature = 201.000 F

	P	FVFO	GORS	DENO	VISO1	VISO2	SPGG	VISG	Z	FVFG
	5014.70	1.2530	505.621	0.7408	0.737	0.768				
	5000.00	1.2532	505.621	0.7407	0.736	0.767				
	4750.00	1.2557	505.621	0.7392	0.722	0.756				
	4500.00	1.2584	505.621	0.7377	0.707	0.745				
	4250.00	1.2611	505.621	0.7361	0.693	0.734				
	4000.00	1.2639	505.621	0.7344	0.678	0.723				
	3750.00	1.2669	505.621	0.7327	0.663	0.712				
	3500.00	1.2700	505.621	0.7309	0.648	0.701				
BPP	3343.36	1.2719	505.621	0.7298	0.638	0.694	0.6523	0.0211	0.9241	0.9198
	3250.00	1.2664	491.229	0.7314	0.647	0.706	0.6510	0.0207	0.9209	0.9429
	3000.00	1.2515	453.042	0.7358	0.672	0.739	0.6476	0.0198	0.9135	1.0133
	2750.00	1.2368	415.349	0.7402	0.699	0.776	0.6444	0.0189	0.9082	1.0990
	2500.00	1.2222	378.083	0.7448	0.727	0.817	0.6415	0.0180	0.9052	1.2048
	2250.00	1.2077	341.178	0.7495	0.757	0.863	0.6390	0.0172	0.9044	1.3375
	2000.00	1.1932	304.575	0.7544	0.789	0.913	0.6372	0.0165	0.9059	1.5072
	1750.00	1.1787	268.217	0.7594	0.823	0.971	0.6361	0.0158	0.9097	1.7298
	1500.00	1.1642	232.046	0.7646	0.858	1.036	0.6361	0.0152	0.9157	2.0314
	1250.00	1.1496	196.003	0.7699	0.896	1.112	0.6378	0.0147	0.9238	2.4591
	1000.00	1.1349	160.006	0.7754	0.935	1.200	0.6422	0.0143	0.9338	3.1073
	750.00	1.1200	123.914	0.7812	0.976	1.305	0.6519	0.0139	0.9456	4.1956
	500.00	1.1047	87.392	0.7872	1.017	1.434	0.6732	0.0136	0.9592	6.3835
	250.00	1.0879	49.162	0.7937	1.061	1.602	0.7333	0.0132	0.9745	12.9713
	150.00	1.0805	32.941	0.7965	1.079	1.687	0.8072	0.0129	0.9810	21.7638
	100.00	1.0762	24.151	0.7981	1.089	1.737	0.8914	0.0127	0.9844	32.7567
	50.00	1.0703	13.166	0.8001	1.102	1.805	1.0912	0.0123	0.9881	65.7620
	25.00	1.0653	5.138	0.8015	1.113	1.858	1.3779	0.0116	0.9905	131.8442
	14.70	1.0617	0.0	0.8025	1.121	1.893	1.6580	0.0111	0.9921	224.6433

```
--- DVA residual oil properties ---
Specific gravity (60.F/60.F) = 0.8529
API gravity                  =   34.41
Molecular weight             =  221.61
```

```
BPP   = Bubble point pressure, psia
P     = Pressure, psia
FVFO  = Oil Formation Volume Factor, bbl/bbl
GORS  = Gas-Oil Ratio, scf/bbl
DENO  = Oil density, g/cc
VISO1 = Oil viscosity, cp (Thodos)
VISO2 = Oil viscosity, cp (Bergman)
SPGG  = Gas specific gravity, Air=1.0
VISG  = Gas viscosity, cp
Z     = Gas compressibility factor
FVFG  = Gas formation volume factor, bbl/Mscf
```

andard conditions for FVFO, GORS, and FVFG are 60.0 F and 14.696 psia

hase equilibria via Amoco Redlich-Kwong Equation of State (ARKES)
all-Yarborough used for Gas Z factor
RKES used for Liquid density

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

DVA for 5 pseudos

Feed: 3 pseudos for c7+

Bubble Point pressure at 201.000 F is 3343.357 psia

Component	Feed	Liquid	Vapor	K value
Nitrogen	1.0300	1.0300	4.0417	3.924E+00
Methane	42.7600	42.7600	89.6202	2.096E+00
Carbon dioxide	0.4800	0.4800	0.5593	1.165E+00
ps1	5.3900	5.3900	4.5246	8.394E-01
ps2	1.9500	1.9500	0.4416	2.265E-01
ps3	15.9188	15.9188	0.7753	4.870E-02
ps4	14.8904	14.8904	0.0363	2.438E-03
ps5	17.5808	17.5808	0.0010	5.830E-05
Total	100.0000	100.0000	100.0000	

Mole percent		100.0000	0.0
Volume percent		100.0000	0.0
Z factor	1.2566	1.2566	0.9241
P/Z, psia			3617.8798
Gas volume factor, bbl/Mscf			0.9198
Molar volume, cf/lb mol	2.6647	2.6647	1.9597
Density, g/cc	0.7298	0.7298	0.1544
Molecular weight	121.4037	121.4037	18.8937
Gas gravity, Air=1.0			0.6523
Pseudocritical temperature, R	869.7334	869.7334	360.5870
Pseudocritical pressure, psia	479.5692	479.5692	658.1252
Pseudocritical volume, cf/lb mol	7.9891	7.9891	1.7003
Viscosity (Thodos), cp		0.6382	0.0211

Phase equilibria via Amoco Redlich-Kwong Equation of State (ARKES)
Hall-Yarborough used for Gas Z factor
ARKES used for Liquid density

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

DVA for 5 pseudos

Component Properties of Feed Stream
Table 1

Component	ID	Mole Weight	Critical Temp R	Critical Pressure psia	Acentric Factor
Nitrogen	1	28.01	227.2	493.1	0.0372
Methane	2	16.04	343.0	666.5	0.0105
Carbon dioxide	3	44.01	547.6	1070.7	0.2310
ps1	256	39.62	622.8	649.3	0.1331
ps2	257	79.99	875.2	460.3	0.2646
ps3	258	118.51	1080.4	440.2	0.3535
ps4	259	190.56	1399.4	287.9	0.5377
ps5	260	358.96	1633.0	156.1	0.8663

Heavy ends characterized by NTYPE characterization method using molecular weight of 228.0 and specific gravity of 0.8685.

A M O C O   P R O D U C T I O N   C O M P A N Y

West Hackberry Field, Gulf Land "D" Well No. 9, (Camerina "C"), LA

DVA for 5 pseudos

Component Properties of Feed Stream
Table 2

Component	Omega a	Omega b	Critical Volume cf/lb mol	Density @ 60F g/cc	Boiling Point F
Nitrogen	0.397549	0.094559	1.43	--	-320.5
Methane	0.446248	0.089117	1.58	--	-258.7
Carbon dioxide	0.399970	0.081033	1.51	--	-109.3
ps1	0.432528	0.087727	2.95	0.4465	-73.8
ps2	0.433754	0.079841	5.16	0.6481	122.1
ps3	0.453158	0.077436	6.90	0.7954	279.7
ps4	0.470217	0.069716	11.84	0.8563	482.3
ps5	0.473603	0.056612	23.71	0.8974	742.0

ARKES parameters via Yarborough-Morris-Turek correlation (1984).
Omega a and omega b are ARKES parameters evaluated at 201.00 F.

AMOCO   PRODUCTION   COMPANY

West Hackberry Field, Gulf Land "D"

Well No. 9, (Camerina "C"), LA

DVA for 5 pseudos

ARKES Binary Interaction Parameters of Feed Stream

i	j	Cij	i	j	Cij	i	j	Cij	i	j	Cij
1	2	0.028000	1	3	-0.055000	1	257	0.189012	1	258	0.186060
1	259	0.120270	1	260	0.010340	2	3	0.206984	2	257	0.010000
2	258	0.036780	2	259	0.036780	2	260	0.001370	3	256	0.183903
3	257	0.151938	3	258	0.142402	3	259	0.105361	3	260	0.075750

i	j	Dij	i	j	Dij	i	j	Dij	i	j	Dij
1	258	0.003000	1	259	0.003000	1	260	-0.022320	2	3	-0.013491
2	258	0.003000	2	259	0.003000	2	260	-0.022320	3	256	-0.014149
3	257	-0.014855	3	258	-0.015333	3	259	-0.016389	3	260	0.006640

Only non-zero binary interaction parameters used in the ARKES are shown.
Component IDs correspond to those in Component Properties Table 1 above.
Binary interaction parameters are evaluated at 201.00 F.

Table A-6: EOS West Hackberry Data

```
1  13    -4     1497.77**********WEST HACKB    0.0000SYSTEM<<<<     0.0000
8   1     0     0     0     0     1     0     1 1.000E-10   0.00
5   1     0     0     0     1              CONCENTRATION = 0.00000E+00
2 3115.000    201.000   3115.000         .000     201.00       0.000    0    PF
*   1  201 0.0000000 0.0000000 1.0000000
  4 4 4  4 4  4 4 4 4 4 1 1 1
3N2     C1    CO2    C2     P1      P2      P3      P4      P5      P6      N2      C1
CO2
    51.430    578.600    713.400   0.546600   0.175000   163.930    3.67
    80.       460.300    875.200   0.648100   0.264600   148.331    5.45
   112.260    459.400   1061.100   0.791000   0.333500   122.377    6.86
   172.610    320.500   1238.700   0.844600   0.506200   122.377   10.68
   244.39     228.86    1561.48    0.870200    0.6699    122.377   15.56
   402.11     138.19    1743.56    0.904700    0.9462    122.377   26.78
    1     2  0.028000    1     3 -0.055000    1     4  0.061000    1     5  0.000000
    1     6  0.189012    1     7  0.16691     1     8  0.10917     1     9  0.05106
    1    10 -0.15689     2     3  0.206984    2     4  0.005000    2     5  0.010000
    2     6  0.010000    2     7  0.01095     2     8  0.01095     2     9  0.01095
    2    10 -0.14689     3     4  0.190287    3     5  0.176010    3     6  0.000000
    3     7  0.146164    3     8  0.113654    3     9  0.080939    3    10  0.09430
    4     5  0.000000    4     6  0.000000    4     7  0.000000    4     8  0.000000
    4     9  0.000000    4    10  0.000000    5     6  0.000000    5     7  0.000000
    5     8  0.000000    5     9  0.000000    5    10  0.000000    6     7  0.000000
    6     8  0.000000    6     9  0.000000    6    10  0.000000    7     8  0.000000
    7     9  0.000000    7    10  0.000000    8     9  0.000000    8    10  0.000000
    9    10  0.000000
7
    1     2  0.000000    1     3  0.000000    1     4  0.000000    1     5  0.000000
    1     6  0.000000    1     7  0.02676     1     8  0.02676     1     9  0.02676
    1    10  0.03222     2     3 -0.013491    2     4  0.000000    2     5  0.000000
    2     6  0.000000    2     7  0.02676     2     8  0.02676     2     9  0.02676
    2    10  0.03222     3     4 -0.013967    3     5 -0.014374    3     6 -0.014855
    3     7 -0.015225    3     8 -0.016152    3     9 -0.017085    3    10 -0.18064
    4     5  0.000000    4     6  0.000000    4     7  0.000000    4     8  0.000000
    4     9  0.000000    4    10  0.000000    5     6  0.000000    5     7  0.000000
    5     8  0.000000    5     9  0.000000    5    10  0.000000    6     7  0.000000
    6     8  0.000000    6     9  0.000000    6    10  0.000000    7     8  0.000000
    7     9  0.000000    7    10  0.000000    8     9  0.000000    8    10  0.000000
    9    10  0.000000
1.0103000   0.4276000 0.0048000 0.0298000 0.0241000 0.0195000 0.130617
 0.1376050 0.0937890 0.1218890 0.8500000 0.0000000 0.1500000
4
3
```

Table A-7: Comparison of Default and Optimized ARKES Description

	Original Description	Optimized
$N_c = 25$	2920	--
$N_c = 8$	3198	3343
$N_c = 10$	3141	3340
Lab	3332	--

Appendix B - Simulation of Coreflood Tests

Two coreflood tests (@ 3500 psi and 2200 psi) were conducted in the laboratory. In these tests, saturated Brea cores with West Hackberry were subjected to flue gas injection (15% CO_2, 85% N_2). The objective of these tests was to use the results of these tests to validate the optimized EOS description.

Table B-1 and B-2 provides the GCOMP input data sets for modeling these two coreflood tests. Only 8-components were used in this simulation. Similar data sets could be generated using PVTCALC and the optimized 10-components description. However, this was not needed since a good match was obtained between the simulation and the experimental results.

Table B-1: First Coreflood, $N_c = 8$, P = 3500 psi
(Bubblepoint Pressure = 3200 psi)

```
* SUMMARY
CC
Simulation of Flue Gas-W.Hack Coreflood 1
Reza Fassihi    - Amoco Production Co
CC
* CONTROL
CC na   naz   nx    ny    nz    nc   ieqs    nw   iunit
    0    0     0    40    1     8     0      2    15
CC   tstart       tstop      mo  dy year  isum      ooip
      .000         7.00       1   1 1994    0          0.
CC   ntchg        delt       dcmax
        2        1.E-05       .010
CC    tdchg       dtmx
         0.        .0010
          .2       .010
CC ips maxi ifap              ap      ptol      tolnr
    0  100    0
CC
N2   C1  CO2 PS1 PS2 PS3 PS4 PS5
CC
* OUTPUT
CC nreg lmass lump    p s k u d m c O M M v k
    0     1     0     0 1 1 0 0 0 0 0 0 0 0 0 0
CC   pressure
 1
 1                        1                    0
    0    0    0    0
CC*************************************************************************CC
CC
CC
CC              PVTCALC GENERATED GCOMP COMPATIBLE OUTPUT
CC
CC Calculation description:
CC    GCOMP compatible output for Nc=8
CC
CC Input stream:
CC    3 pseudos for c7+
CC
CC*************************************************************************CC
CC*************************************************************************CC
CC
CC   SECTION 1 - Component Names
CC
CC   GCOMP Name     PVTCALC Name
CC   ----------     ------------
CC      N2          Nitrogen
CC      C1          Methane
CC     CO2          Carbon dioxide
CC     PS1          ps1
CC     PS2          ps2
CC     PS3          ps3
CC     PS4          ps4
CC     PS5          ps5
CC
CC
CC*************************************************************************CC
CC*************************************************************************CC
CC
CC   SECTION 2 - Fluid Property Section
CC
* FLUID PROPERTY
```

```
CC
CC
CC   Water viscosity, density, reference pressure, and compressibility
CC   ( calculated with BRINE program using a salinity of 50000.0 ppm )
CC        uw         rhow        pref         cw
      0.34        62.58      2000.00    2.93E-06
CC          ivisc=0 ===> ARKES liquid densities used in
CC                       Thodos viscosity correlation
CC        ivisc
THODOS       0
CC   jspec integers
     0    0    1    0    1    0    0    0    0    0
CC   aspec variables
       0.0        0.0         0.0          0.0          0.0          0.0
CC   Reservoir Temperature
      201.0
$ ALL COMPONENTS
CC   k               amw        crtp        crtt        rho         alk        crtv
     1             28.01       493.1       227.2      0.5300      0.0372       1.43
     2             16.04       666.4       343.0      0.3000      0.0105       1.58
     3             44.01      1070.7       547.6      0.8172      0.2310       1.51
     4             39.62       649.3       622.8      0.4465      0.1331       2.95
     5             79.99       460.3       875.2      0.6481      0.2646       5.16
     6            118.51       440.2      1080.4      0.7954      0.3535       6.90
     7            190.56       287.9      1399.4      0.8563      0.5377      11.84
     8            358.96       156.1      1633.0      0.8974      0.8663      23.71
CC inter nsc nsco
     1    28     8
CC   i    j     C(i,j)      D(i,j)
     1    2    0.02800     0.0
     1    3   -0.05500     0.0
```

```
     1     4     0.0          0.0
     1     5     0.18901      0.0
     1     6     0.18606      0.00300
     1     7     0.12027      0.00300
     1     8     0.01034     -0.02232
     2     3     0.20698     -0.01349
     2     4     0.0          0.0
     2     5     0.01000      0.0
     2     6     0.03678      0.00300
     2     7     0.03678      0.00300
     2     8     0.00137     -0.02232
     3     4     0.18390     -0.01415
     3     5     0.15194     -0.01485
     3     6     0.14240     -0.01533
     3     7     0.10536     -0.01639
     3     8     0.07575      0.00664
     4     5     0.0          0.0
     4     6     0.0          0.0
     4     7     0.0          0.0
     4     8     0.0          0.0
     5     6     0.0          0.0
     5     7     0.0          0.0
     5     8     0.0          0.0
     6     7     0.0          0.0
     6     8     0.0          0.0
     7     8     0.0          0.0
```

```
CC   i       omega a     omega b
     1     0.3975485   0.0945589
     2     0.4462476   0.0891166
     3     0.3999700   0.0810329
     4     0.4325274   0.0877264
     5     0.4337538   0.0798408
     6     0.4531575   0.0774353
     7     0.4702161   0.0697158
     8     0.4736027   0.0566122
CC nsep        swden   iskden
     1          64.53      1
CC
CC Separator 1 at 15.0 psia and 70.0 F
CC
CC    psep        tsep
      15.0        70.0
CC   i       omega a     omega b
     1     0.4307751   0.0935859
     2     0.4529683   0.0887474
     3     0.3998279   0.0772972
     4     0.4186541   0.0813023
     5     0.4454129   0.0800844
     6     0.4553232   0.0764474
     7     0.4666198   0.0681949
     8     0.4695099   0.0550860
CC
```

```
CC*******************************************************************CC
* RELATIVE PERMEABILITY AND CAPILLARY PRESSURE                                    RK1
CC
     1       ISTONE=1   USE STONE'S METHOD 1 FOR 3 PHASE RELPERMS     RK2          RK2
CC ISET IWET      SOM
     1    1        0.                                                              RK3
CC
```

```
CC ---Water/oil relative perm.
CC

    2        NO. OF WATER/OIL RELATIVE PERM DATA                    RK4        RK4
CC
CC      SW          KROW         KRW        RKGW        RKOH      RKWH      PCW RK5
       0.000        1.000       0.00
       1.000        0.000       1.00
CC
CC 21       NO. OF GAS/OIL RELATIVE PERM DATA                       RK6        RK6
CC
CC  LAND'S THREE PHASE RELATIVE PERM CURVES
CC
CC      SG          KROG         KRG     RKGH          PCG
CC                                DRAINAGE IMBIBITION
CC    0.000         1.0         0.000
CC    0.030        0.916        0.001
CC    0.050        0.860        0.005
CC    0.100        0.730        0.015
CC    0.150        0.620        0.025
CC    0.200        0.510        0.037
CC    0.250        0.420        0.055
CC    0.300        0.340        0.077
CC    0.350        0.265        0.100
CC    0.400        0.205        0.135
CC    0.450        0.150        0.175
CC    0.500        0.110        0.220
CC    0.550        0.075        0.280
CC    0.600        0.047        0.350
CC    0.650        0.025        0.430
CC    0.700        0.010        0.530
CC    0.750       0.0055        0.670
CC    0.800       0.0010        0.870
CC    0.850       0.0005        0.970
CC    0.900         0.0         0.990
CC    1.000         0.0         1.000
CC
    17        NO. OF GAS/OIL RELATIVE PERM DATA                     RK6        RK6
CC
CC  MJOAK   THREE PHASE RELATIVE PERM CURVES
CC
CC      SG          KROG         KRG     RKGH          PCG
CC                                DRAINAGE IMBIBITION
     0.000       1.0000        0.0000
     0.025        .98100       0.00010
     0.050        .96200       0.00100
     0.100        .92600        0.0100
     0.150        .79400        0.0400
     0.200        .63100        0.093
     0.250        .42900        0.147
     0.300        .27100        0.200
     0.350        .15800        0.251
     0.400        .07940        0.341
     0.450        .03410        0.430
     0.500        .01170        0.500
     0.550        .00430        0.630
     0.600        .00125        0.735
     0.650        .00034        0.794
     0.700        .00010        0.860
     0.750        .00000        1.000
CC   0.800        .00000        1.000
```

```
CC
CC
* GRID DIMENSION                                                              GD1    GD1
CC
CC CONSTANT SIZED GRID TOTALLING  8.00 FT. IN THE Y DIRECTION
CC  IPROC
    1               DISTANCE BETWEEN GRIDS IS  CONSTANT
CC  Y-lenght
       8.                                       Y-LENGTH
CC  NX
    1               CONSTANT NOT VARIABLE
CC X-lenght : grid lenght in x direction
0.1459                                          X-LENGTH
CC      xtd          ytd          angd
        0.           0.           0.            GRID ROT/TRANS GD15
CC    datum         dorg         amxd         adip
        0.           0.           0.           0.    MODEL IS HORIZONTAL
* DEPTH
CC nsp idpr      dmin         dmax  izd inet
    0   1         0.           0.    1    0
CC iproc k1  k2             factr        min         max
     1   1   1               0.          0.          0.
     0.              CONSTANT DEPTH AT TOP OF LAYER 1
* THICKNESS
CC NS   IHPR
    0    1
CC iproc k1  k2             factr        min         max
     1   1   1               0.          0.          0.
0.1459                              THICKNESS, FEET
* POROSITY
CC nsp ipopr pomn        pomx       iphpr phmn        phmx
    0   1                              0
CC iproc k1  k2             factr        min         max
     1   1   1               0.          0.          0.
    .19470                             POROSITY
CC
CC
* Y OR R PERMEABILITY
CC NSP IYKP        MIN        MAX    IKHP      MIN         MAX
    0   1          0.         0.      1        0.          0.
CC iproc k1  k2             factr        min         max
     3   1   1               0.          0.          0.
CC NTX  NTY ITROT
    1    4   1
        0.           1.
        0.           4.          4.01          8.
      453.         453.        453.          453.
CC
CC
CC
* DISPERSION
CC
CC IDISP IPOTD
     0     1
CC nsp ipr
    0   1
CC iproc
    1    1     1
CC
CC Physical dispersivity coefficients
```

```
CC
CC alpha oil
      .100
CC nsp ipr
     0     1
CC iproc
     1     1     1
CC alpha gas
       .100
CC nsp ipr
     0     1
CC iproc
     1     1     1
CC alpha H2O
       .100
* PRESSURE                                                       PR1       PR1
CC NSPEC
     0
CC iproc k1  k2              fact.       min        max
     1     1     1
      3500.
* AQUEOUS SATURATION
     0
CC iproc k1  k2              fact.       min        max
     1     1     1
CC
          0.           Initial water saturation distribution
CC***********************************************************************CC
CC***********************************************************************CC
CC
CC   SECTION 3 - Initialization Section
CC
* INITIALIZATION
CC
CC
CC N2     overall fraction
CC
     0
     1
0.01030000
CC
CC C1     overall fraction
CC
     0
     1
0.42760000
CC
CC CO2    overall fraction
CC
     0
     1
0.00480000
CC
CC PS1    overall fraction
CC
     0
     1
0.05390000
CC
CC PS2    overall fraction
```

```
CC
     0
     1
0.01950000
CC
CC PS3   overall fraction
CC
     0
     1
0.15918752
CC
CC PS4   overall fraction
CC
     0
     1
0.14890426
CC
CC PS5   overall fraction
CC
     0
     1
0.17580822
CC
CC***************************************************************CC
CC***************************************************************CC
CC***************************************************************CC
* RATE
& WELL INFORMATION
WINFO    1 P-1   0 0 0 0                    0.       8.       1.   0.
WINFO    2 I-1   0 0 0 0                    0.       0.       1.   0.
& INJECTED FLUID COMPOSITIONS
IFC2     1     .85        0.      .15      0.       0.       0.
               0.         0.
& RATE CONTROLS
FCTLID                              FIELD SCHEDULE
FCTL1    1 0 0 0          1      0      0
FCTL2             0.4
FRTIME            0.1          0.
PWELL    1 P-1   0                3500.      9999.   1.   1.   0.
IWELL    2 I-1 0 1 1 1 0 1 1      9999. 9.8955E-4        0.        0.
FCTL3                    7.
FCTLID                              FIELD SCHEDULE
FCTL1  100    0 0
```

Table B-2: Second Coreflood, $N_c = 8$, P = 2200 psi (Flashed @ 2000 psi before pressurizing to 2200 psi)

```
* SUMMARY
CC
Simulation of Flue Gas-W.Hack Coreflood 2
Reza Fassihi    - Amoco Production Co
CC
* CONTROL
CC na    naz   nx    ny    nz    nc  ieqs   nw   iunit
    0    0     0     40    1     8    0     2    15
CC   tstart        tstop      mo  dy year  isum       ooip
      .000          7.00       1   1 1994    0          0.
CC    ntchg        delt       dcmax
          2      1.E-05         .010
CC   tdchg        dtmx
          0.         .0010
          .2         .010
CC ips maxi ifap              ap      ptol      tolnr
    0  100    0
CC
N2   C1   CO2 PS1 PS2 PS3 PS4 PS5
CC
* OUTPUT
CC nreg lmass lump   p s k u d m c O M M v k
    0    1     0     0 1 1 0 0 0 0 0 0 0 0 0
CC  pressure
 1
 1                      1                     0
    0    0     0     0
CC***************************************************************CC
CC
CC              PVTCALC GENERATED GCOMP COMPATIBLE OUTPUT
CC
CC Calculation description:
CC    GCOMP compatible output for FB4
CC
CC Input stream:
CC    Liquid from DVA for 5 pseudos
CC
CC***************************************************************CC
CC***************************************************************CC
CC
CC   SECTION 1 - Component Names
CC
CC   GCOMP Name    PVTCALC Name
CC   ----------    ------------
CC      N2         Nitrogen
CC      C1         Methane
CC      CO2        Carbon dioxide
CC      PS1        ps1
CC      PS2        ps2
CC      PS3        ps3
CC      PS4        ps4
CC      PS5        ps5
CC
N2   C1   CO2 PS1 PS2 PS3 PS4 PS5
CC
CC***************************************************************CC
CC***************************************************************CC
CC
CC   SECTION 2 - Fluid Property Section
CC
```

```
*  FLUID PROPERTY
CC
CC
CC   Water viscosity, density, reference pressure, and compressibility
CC   ( calculated with BRINE program using a salinity of 50000.0 ppm )
CC       uw        rhow       pref        cw
      0.36       62.83     2000.00    2.89E-06
CC            ivisc=0  ===>  ARKES liquid densities used in
CC                           Thodos viscosity correlation
CC          ivisc
THODOS          0
CC   jspec integers
     0     0     0     0     0     0     0     0     0     0
CC   aspec variables
        0.0         0.0         0.0         0.0         0.0         0.0
CC   Reservoir Temperature
      190.0
$ ALL COMPONENTS
CC    k            amw       crtp        crtt        rho        alk       crtv
      1          28.01      493.1       227.2      0.5300     0.0372      1.43
      2          16.04      666.4       343.0      0.3000     0.0105      1.58
      3          44.01     1070.7       547.6      0.8172     0.2310      1.51
      4          39.62      649.3       622.8      0.4465     0.1331      2.95
      5          79.99      460.3       875.2      0.6481     0.2646      5.16
      6         118.51      440.2      1080.4      0.7954     0.3535      6.90
      7         190.56      287.9      1399.4      0.8563     0.5377     11.84
      8         358.96      156.1      1633.0      0.8974     0.8663     23.71
CC inter nsc nsco
      1    28     8
```

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```
CC   i      j      C(i,j)      D(i,j)
     1      2     0.02800      0.0
     1      3    -0.05500      0.0
     1      4     0.0          0.0
     1      5     0.18901      0.0
     1      6     0.18606      0.00300
     1      7     0.12027      0.00300
     1      8     0.01144     -0.02122
     2      3     0.20210     -0.01633
     2      4     0.0          0.0
     2      5     0.01000      0.0
     2      6     0.03678      0.00300
     2      7     0.03678      0.00300
     2      8     0.00247     -0.02122
     3      4     0.18045     -0.01609
     3      5     0.15002     -0.01583
     3      6     0.14152     -0.01565
     3      7     0.10663     -0.01535
     3      8     0.08085      0.01009
     4      5     0.0          0.0
     4      6     0.0          0.0
     4      7     0.0          0.0
     4      8     0.0          0.0
     5      6     0.0          0.0
     5      7     0.0          0.0
     5      8     0.0          0.0
     6      7     0.0          0.0
     6      8     0.0          0.0
     7      8     0.0          0.0
CC   i         omega a     omega b
     1        0.4006423   0.0944899
     2        0.4473614   0.0891057
     3        0.3996499   0.0805975
     4        0.4325274   0.0877264
     5        0.4351342   0.0799196
     6        0.4538411   0.0773652
     7        0.4702172   0.0695953
     8        0.4734441   0.0564850
CC nsep          swden  iskden
     1           64.53     1
CC
CC Separator 1 at 15.0 psia and 70.0 F
CC
CC     psep        tsep
       15.0        70.0
CC   i         omega a     omega b
     1        0.4307751   0.0935859
     2        0.4529683   0.0887474
     3        0.3998279   0.0772972
     4        0.4186541   0.0813023
     5        0.4454129   0.0800844
     6        0.4553232   0.0764474
     7        0.4666198   0.0681949
     8        0.4695099   0.0550860
CC
CC************************************************************************CC
CC************************************************************************CC
*  RELATIVE PERMEABILITY AND CAPILLARY PRESSURE                                    RK1
CC
```

```
1       ISTONE=1  USE STONE'S METHOD 1 FOR 3 PHASE RELPERMS
ISET IWET      SOM                                                        RK3
1    1         0.
```

---Water/oil relative perm.

```
2       NO. OF WATER/OIL RELATIVE PERM DATA
```

SW	KROW	KRW	RKGW	RKOH	RKWH	PCW RK5
0.000	1.000	0.00				
1.000	0.000	1.00				

```
21      NO. OF GAS/OIL RELATIVE PERM DATA
```

LAND'S THREE PHASE RELATIVE PERM CURVES

SG	KROG	KRG	RKGH	PCG
		DRAINAGE IMBIBITION		
0.000	1.0	0.000		
0.030	0.916	0.001		
0.050	0.860	0.005		
0.100	0.730	0.015		
0.150	0.620	0.025		
0.200	0.510	0.037		
0.250	0.420	0.055		
0.300	0.340	0.077		
0.350	0.265	0.100		
0.400	0.205	0.135		
0.450	0.150	0.175		
0.500	0.110	0.220		
0.550	0.075	0.280		
0.600	0.047	0.350		
0.650	0.025	0.430		
0.700	0.010	0.530		
0.750	0.0055	0.670		
0.800	0.0010	0.870		
0.850	0.0005	0.970		
0.900	0.0	0.990		
1.000	0.0	1.000		

```
17      NO. OF GAS/OIL RELATIVE PERM DATA
```

MJOAK THREE PHASE RELATIVE PERM CURVES

SG	KROG	KRG	RKGH	PCG
		DRAINAGE IMBIBITION		
0.000	1.0000	0.0000		
0.025	.98100	0.00010		
0.050	.96200	0.00100		
0.100	.92600	0.0100		
0.150	.79400	0.0400		
0.200	.63100	0.093		
0.250	.42900	0.147		
0.300	.27100	0.200		
0.350	.15800	0.251		
0.400	.07940	0.341		
0.450	.03410	0.430		
0.500	.01170	0.500		
0.550	.00430	0.630		
0.600	.00125	0.735		

```
          0.650   .00034        0.794
          0.700   .00010        0.860
          0.750   .00000        1.000
CC   0.800   .00000        1.000
CC
CC
* GRID DIMENSION                                                      GD1     GD1
CC
CC CONSTANT SIZED GRID TOTALLING  8.00 FT. IN THE Y DIRECTION
CC   IPROC
     1                   DISTANCE BETWEEN GRIDS IS  CONSTANT
CC  Y-lenght
        8.                                        Y-LENGTH
CC  NX
     1               CONSTANT NOT VARIABLE
CC X-lenght : grid lenght in x direction
0.1459                                           X-LENGTH
CC       xtd        ytd        angd
         0.         0.         0.              GRID ROT/TRANS GD15
CC    datum       dorg       amxd       adip
      0.          0.         0.         0.     MODEL IS HORIZONTAL
* DEPTH
CC nsp idpr      dmin       dmax  izd inet
   0    1        0.         0.     1    0
CC iproc k1   k2              factr       min        max
   1    1    1               0.         0.         0.
   0.              CONSTANT DEPTH AT TOP OF LAYER 1
* THICKNESS
CC NS   IHPR
   0    1
CC iproc k1   k2              factr       min        max
   1    1    1               0.         0.         0.
0.1459                              THICKNESS, FEET
* POROSITY
CC nsp ipopr pomn      pomx      iphpr phmn       phmx
   0    1                            0
CC iproc k1   k2              factr       min        max
   1    1    1               0.         0.         0.
   .19470                            POROSITY
CC
CC
* Y OR R PERMEABILITY
CC NSP IYKP      MIN        MAX     IKHP     MIN        MAX
   0    1       0.         0.       1       0.         0.
CC iproc k1   k2              factr       min        max
   3    1    1               0.         0.         0.
CC NTX  NTY ITROT
   1    4    1
        0.         1.
        0.         4.       4.01       8.
     453.        453.       453.       453.
CC
CC
CC
* DISPERSION
CC
CC IDISP IPOTD
   0    1
CC nsp ipr
   0    1
```

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```
CC iproc
    1    1    1
CC
CC Physical dispersivity coefficients .
CC
CC alpha oil
      .100
CC nsp ipr
    0    1
CC iproc
    1    1    1
CC alpha gas
      .100
CC nsp ipr
    0    1
CC iproc
    1    1    1
CC alpha H2O
      .100
*  PRESSURE                                                    PR1    PR1
CC NSPEC
     0
CC iproc k1  k2              fact.        min        max
    1    1    1
    2200.
* AQUEOUS SATURATION
     0
CC iproc k1  k2              fact.        min        max
    1    1    1
CC
        0.            Initial water saturation distribution
CC*******************************************************************CC
CC*******************************************************************CC
CC
CC   SECTION 3 - Initialization Section
CC
* INITIALIZATION
CC
CC
CC N2    overall fraction
CC
     0
     1
0.00474050
CC
CC C1    overall fraction
CC
     0
     1
0.31389850
CC
CC CO2   overall fraction
CC
     0
     1
0.00443900
CC
CC PS1   overall fraction
CC
     0
```

```
              1
0.05571000
CC
CC PS2   overall fraction
CC
       0
       1
0.02327200
CC
CC PS3   overall fraction
CC
       0
       1
0.19591000
CC
CC PS4   overall fraction
CC
       0
       1
0.18434300
CC
CC PS5   overall fraction
CC
       0
       1
0.21768700
CC
CC***********************************************************************CC
CC***********************************************************************CC
* RATE
& WELL INFORMATION
WINFO    1 P-1   0 0 0 0                    0.        8.          1.   0.
WINFO    2 I-1   0 0 0 0                    0.        0.          1.   0.
& INJECTED FLUID COMPOSITIONS
IFC2      1      .85       0.       .15     0.        0.         0.
                 0.        0.
& RATE CONTROLS
FCTLID                                 FIELD SCHEDULE
FCTL1    1 0 0 0          1       0      0
FCTL2              0.4
FRTIME             0.1           0.
PWELL    1 P-1   0                   2200.     9999.   1.   1.   0.
IWELL    2 I-1 0 1 1 1 0 1 1         9999. 9.8955E-4         0.         0.
FCTL3                     7.
FCTLID                                 FIELD SCHEDULE
FCTL1   100    0 0
```

SIMULATION OF THE WEST HACKBERRY OIL AIR INJECTION COMBUSTION TUBE TESTS

A REPORT SUBMITTED TO
THE AMOCO PRODUCTION COMPANY RESEARCH DEPARTMENT
TULSA PRODUCTION RESEARCH DIVISION

BY

JOHN D.M. BELGRAVE, Ph.D., P.Eng.
UNIVERSITY OF CALGARY

JUNE 26, 1995

SUMMARY

This report describes the development of composition dependent K-Values for flue gas/West Hackberry oil systems and their validation in the history matching of two coreflood displacements tests conducted with a 85 %N_2 / 15 %CO_2 gas mixture. The purpose of this oil characterization was to aid in the modelling of the West Hackberry oil displacement by air injection.

ARC and combustion tube data are consolidated within the report to formulate a reaction model for the prediction of air injection performance. Several numerical stability problems were encountered that were addressed within the framework of computational ease and adherence as much as possible to the experimental data.

The simulations of the air injection experiments were able to match oil and gas production, but accelerated the water production indicating the need to input strong water-oil capillary pressures. The experimentally observed trends in effluent oxygen concentration in the produced gas stream was captured, but the magnitude of the produced oxygen was over predicted. This was due to an inability to increase the oxidation rate owing to a very narrow radius of convergence of this problem. Peak temperatures for the most part were well represented by the model but indicated a need to have a more comprehensive treatment with respect to radial energy transfers to and from the sand pack.

Recommendations are also included in the report.

TABLE OF CONTENTS

1.0 INTRODUCTION

This report describes the one-dimensional history matching simulations of the West Hackberry oil combustion tube experiments using the Computer Modelling Group's (CMG) thermal numerical reservoir simulator, STARS.

It first discusses the generation of composition dependent K-Values to characterize the thermodynamic behaviour of the West Hackberry oil and the validation of this characterization by history matching the performance of two flue gas/oil displacement experiments with STARS.

ARC (Accelerating Rate Calorimetry) test data were then combined with the combustion tube data to formulate a kinetic description of the oil's oxidation characteristics. Owing to the formulation of STARS and the significant nonlinearity of the input data (mainly due to the oxidation kinetics coupled with the composition dependent K-Values), the radius of convergence of the combustion tube simulation problem based on the ARC Arrhenius kinetic parameters is small. This resulted in STARS taking very small time step sizes, and many time crashing, during the runs. This problem was addressed by adjusting the ARC pre-exponential frequency factor and reaction order with respect to oil concentration until a mathematically stable and experimentally consistent oxidation zone could be propagated.

2.0 OIL CHARACTERIZATION

The oil characterization used in this work was developed from EOS (Equation-of-State) numerical simulations of the flue gas displacement experiments[1] by M.R. Fassihi[2] using Scientific Software-Intercomp's (SSI) compositional simulator, GCOMP.

In Fassihi's report laboratory measured PVT and oil-flue gas mixture data were first used in an EOS optimization program to tune the EOS parameters for an eight-component and a ten-component oil description. Both descriptions provided a good description of the laboratory PVT data. Table 1 shows the final EOS parameters and oil phase component densities at standard

Table 1: Component critical properties and liquid densities.			
Component	Molecular Mass (lb/lbmol)	Critical Temp. (°F)	Critical Press. (Psia)	Liquid Density at std. cond. (lb/ft³)
N_2	28.10	-232.47	493.1	50.56
C_1	16.04	-116.67	666.4	18.72
CO_2	44.01	87.93	1070.7	51.19
C_2-C_4	39.62	163.13	649.3	27.87
C_5-C_6	79.99	415.53	460.3	40.46
C_7-C_{11}	118.51	620.73	440.2	49.46
C_{12}-C_{17}	190.56	939.73	287.9	53.46
C_{18+}	358.96	1173.33	156.1	56.02

conditions obtained for the eight-component description.

The report also contained optimized oil and gas phase component viscosity data as a function of temperature, and these data are shown in Table 2. Rather than input these viscosity data directly into STARS in its tabular form, smooth analytical viscosity functions of the form supported by STARS were fitted to the data. An important advantage to this is that it avoids the abrupt change in the viscosity-temperature gradient associated with the endpoints of the table. For the oil phase the analytical function is given by

$$\mu_i = A_i e^{\frac{B_i}{T}} \tag{1}$$

and for the gas phase

$$\mu_i = A_i T^{B_i} \tag{2}$$

where T is the absolute temperature. The coefficients obtained for use with Eqs. 1 and 2 are given in Table 3.

The eight-component model was successfully used by Fassihi to history match the two flue gas coreflood tests. Run 1 was conducted at 3500 psia and 200°F, and Run 2 at 2200 psia and 190°F. Both experiments used a flue gas mixture of 85% N_2 and 15% CO_2. From the simulation results K-values of different components were generated and cross-correlated against the mole

Table 2: Viscosity of oil components at different temperatures.				
Component	Oil Phase (cp)	Temp. (°F)	Phase (cp)	Temp. (°F)
N_2	0.2235 0.11	200 400	0.165 0.362	280 400
C_1	0.2213 0.11	200 400	0.0257 0.0362	280 400
CO_2	0.0489 0.0324	200 400	0.0245 0.0486	280 400
C_2-C_4	0.0565 0.0363	200 400	0.0245 0.0488	280 400
C_5-C_6	0.1836 0.09	200 400	0.0245 0.0488	280 400
C_7-C_{11}	0.6698 0.2858	200 400	0.0245 0.0488	280 400
C_{12}-C_{17}	1.5508 0.6067	200 400	0.0245 0.0488	280 400
C_{18+}	17.4568 5.2398	200 400	0.023 0.07	280 400

fraction of nitrogen in the oil phase, X_{N_2}, using the following relationship

$$\frac{\log K_i(X_{N_2})}{\log K_i(X_{N_2}=0)} = a + b X_{N_2} \tag{3}$$

Table 3: Oil and gas phase viscosity coefficients.				
Component	Oil Phase (cp)		Gas Phase (cp)	
	A_i	B_i	A_i	B_i
N_2	0.0106140	2010.2	1.6746E-16	5.2260
C_1	0.0109660	1982.1	7.4588E-09	2.2786
CO_2	0.0083353	1167.1	2.0806E-15	4.5559
C_2-C_4	0.0084364	1254.5	2.0806E-15	4.5559
C_5-C_6	0.0085699	2021.6	1.7370E-15	4.5832
C_7-C_{11}	0.0172210	2415.0	1.7370E-15	4.5832
C_{12}-C_{17}	0.0274550	2661.1	1.7370E-15	4.5832
C_{18+}	0.0989540	3412.4	1.5250E-23	7.4030

2.1 Estimation of K-Values

The K-Value data generated in the Fassihi report for the eight-component model are shown in Table 4. The coefficients in Eq. 3 that account for the K-Value compositional dependence on oil phase nitrogen mole fraction are also provided in this table.

It should be noted that the K-Values reported in Table 4 are those corresponding to a nitrogen mole fraction of zero in the oil phase. To simulate the air injection experiments these data had to be extrapolated over a broader range of temperature, pressure and nitrogen oil phase mole fraction. This was achieved by first fitting the above data and then expanding its temperature and pressure range with a modified form of Antoine's equation (for vapour pressure estimation) as follows:

$$K_i = \left(\frac{a}{P} + b\,P \right) e^{\left[\frac{-c}{T\,+\,d} \right]} \tag{4}$$

Table 4: K-Values of West Hackberry Oil from Fassihi Report

Comp. Name	K-Value at 2000 psia		K-Value at 3000 psia		$\dfrac{\log K_i(X_{N_2})}{\log K_i(X_{N_2}=0)} = a + b\,X_{N_2}$	
	200°F	400°F	200°F	400°F	a	b
N_2	6.26	4.992	4.326	3.5	1	0.7425
C_1	2.922	2.985	2.237	2.225	1	0
CO_2	1.532	1.572	1.225	1.238	1	3.9829
C_2-C_4	0.8823	1.337	0.8398	1.121	1	14.8236
C_5-C_6	0.1557	0.4357	0.2059	0.4369	1	3.9086
C_7-C_{11}	2.30E-02	0.1308	4.06E-02	0.1538	1	3.0547
C_{12}-C_{17}	4.42E-04	8.76E-03	1.64E-03	1.58E-02	1	2.5149
C_{18+}	2.40E-06	2.51E-04	2.81E-05	8.50E-04	1	2.1871

where a, b, c, and d are regression coefficients and P and T absolute pressure and temperature respectively. The calculated K-Values and EOS K-Values are compared in Figure 1. Except at the low end of the K-Value range Eq. 4 represented the data quite well. This equation permitted extrapolation of the data through the temperature range 60 to 1000°F and pressures over 2000 to 4000 psia. Extrapolation below 2000 psi produced unphysical results owing to the limited number of starting data points. With this expanded table the composition dependence was generated using Eq. 3, for values of X_{N_2} ranging from 0.0 to 0.25. Tables 5 through 12 are the resulting composition dependent K-Values for the eight oil components.

Figure 1. Regression of EOS K-Values
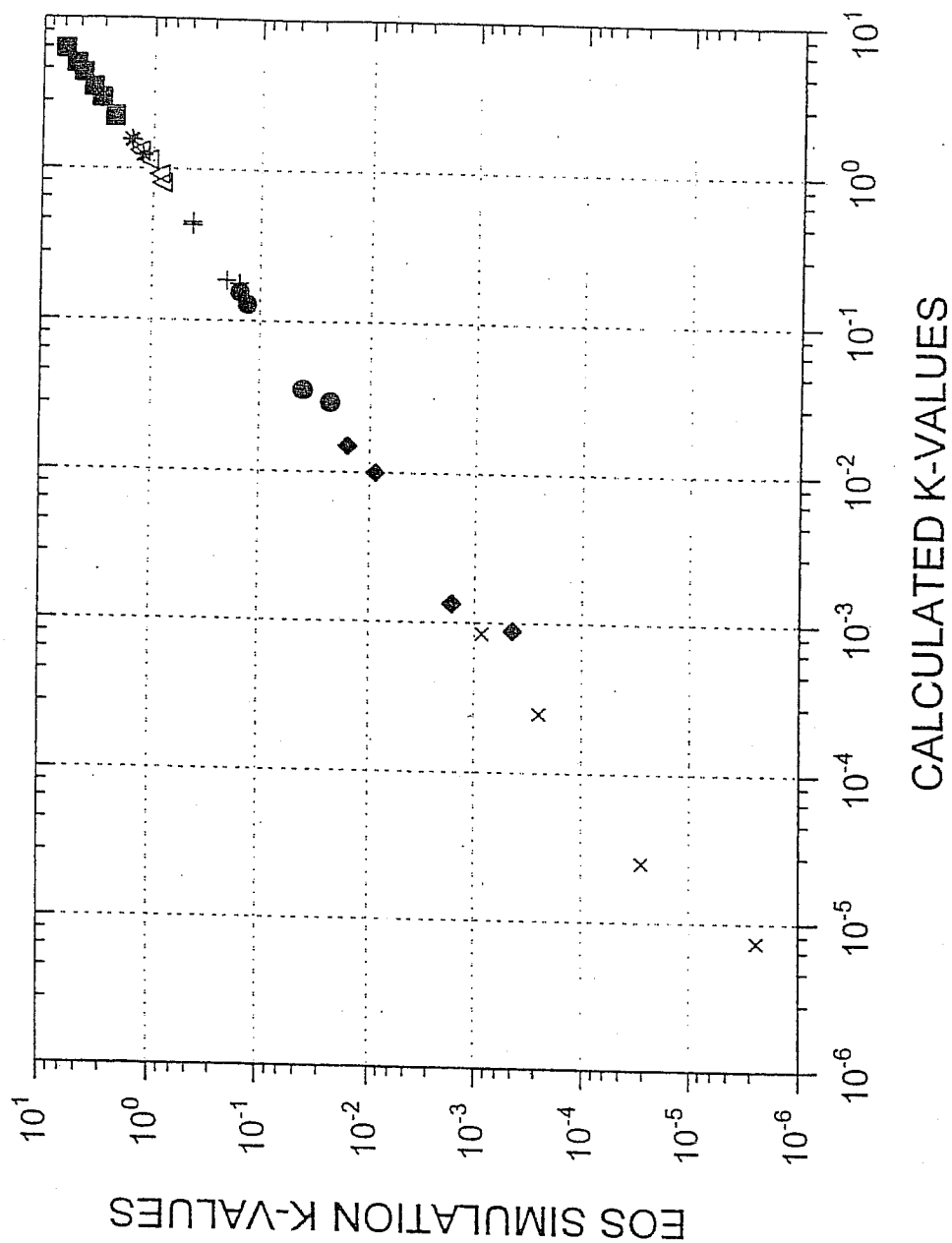
Table 5: K-Values for N$_2$				
Temp. °F	X$_{N2}$	K-Values at		
		2000 psia	3000 psia	4000 psia
60	0.00	17.36134	12.06577	9.56544
216		6.0394	4.19725	3.32748
373		5.08641	3.53495	2.80242
530		4.7408	3.29475	2.612
686		4.56266	3.17096	2.51386
843		4.45409	3.0955	2.45404
1000		4.38101	3.04471	2.41377
60	0.05	19.30202	13.23451	10.40193
216		6.45636	4.42683	3.47936
373		5.40303	3.70461	2.91171
530		5.02276	3.44387	2.70678
686		4.82716	3.30976	2.60138
843		4.70809	3.22812	2.5372
1000		4.628	3.1732	2.49404
60	0.10	21.45963	14.51645	11.31156
216		6.90212	4.66896	3.63817
373		5.73935	3.88241	3.02526
530		5.32149	3.59974	2.805
686		5.107	3.45465	2.69194
843		4.97656	3.36642	2.62319
1000		4.8889	3.30712	2.57698
60	0.15	23.85843	15.92257	12.30074
216		7.37865	4.92434	3.80422
373		6.09661	4.06874	3.14324
530		5.63799	3.76266	2.90679
686		5.40305	3.60587	2.78566
843		5.26035	3.51064	2.71209
1000		5.16452	3.44668	2.66268
60	0.20	26.52537	17.46489	13.37642
216		7.88808	5.19368	3.97786
373		6.4761	4.26401	3.26582
530		5.97331	3.93296	3.01227
686		5.71627	3.76372	2.88264
843		5.56032	3.66104	2.804
1000		5.45567	3.59214	2.75123
60	0.25	29.49042	19.15661	14.54617
216		8.43268	5.47776	4.15942
373		6.87922	4.46866	3.39318
530		6.32858	4.11097	3.12158
686		6.04764	3.92847	2.983
843		5.8774	3.81789	2.89903
1000		5.76324	3.74373	2.84272

Table 6: K-Values for C_1				
Temp. °F	X_{N2}	K-Values at		
		2000 psia	3000 psia	4000 psia
60	0.00	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334
60	0.05	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334
60	0.10	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334
60	0.15	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334
60	0.20	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334
60	0.25	2.78885	2.10646	1.83944
216		2.94163	2.22186	1.94021
373		2.96828	2.24198	1.95778
530		2.97934	2.25034	1.96508
686		2.9854	2.25492	1.96908
843		2.98923	2.25781	1.9716
1000		2.99186	2.2598	1.97334

Table 7: K-Values for CO_2				
Temp. °F	X_{N2}	K-Values at		
		2000 psia	3000 psia	4000 psia
60	0.00	1.40398	1.11397	1.02235
216		1.5413	1.22292	1.12234
373		1.56525	1.24192	1.13978
530		1.5752	1.24981	1.14703
686		1.58065	1.25414	1.151
843		1.58409	1.25687	1.1535
1000		1.58646	1.25875	1.15523
60	0.05	1.50213	1.13817	1.02686
216		1.67998	1.27292	1.14843
373		1.71133	1.29667	1.16987
530		1.72438	1.30657	1.17879
686		1.73154	1.31199	1.18368
843		1.73606	1.31542	1.18677
1000		1.73918	1.31778	1.1889
60	0.10	1.60715	1.1629	1.03139
216		1.83113	1.32497	1.17514
373		1.87104	1.35385	1.20075
530		1.8877	1.3659	1.21144
686		1.89684	1.37251	1.2173
843		1.90261	1.37669	1.22101
1000		1.90659	1.37957	1.22356
60	0.15	1.7195	1.18816	1.03594
216		1.99589	1.37914	1.20246
373		2.04566	1.41354	1.23244
530		2.06648	1.42792	1.24499
686		2.07791	1.43582	1.25187
843		2.08514	1.44082	1.25623
1000		2.09013	1.44426	1.25923
60	0.20	1.8397	1.21397	1.04051
216		2.17547	1.43554	1.23042
373		2.23658	1.47586	1.26498
530		2.26219	1.49276	1.27946
686		2.27627	1.50206	1.28743
843		2.28518	1.50793	1.29247
1000		2.29133	1.51199	1.29594
60	0.25	1.96831	1.24035	1.0451
216		2.37121	1.49424	1.25902
373		2.44531	1.54093	1.29837
530		2.47644	1.56055	1.3149
686		2.49357	1.57134	1.32399
843		2.50441	1.57818	1.32975
1000		2.51189	1.58289	1.33372

Temp. °F	X_{N2}	K-Values at 2000 psia	K-Values at 3000 psia	K-Values at 4000 psia
60	0.00	0.16126	0.14097	0.14087
216		0.96869	0.84682	0.84619
373		1.28015	1.1191	1.11827
530		1.43366	1.25329	1.25236
686		1.62444	1.33265	1.33166
843		1.58431	1.38499	1.38396
1000		1.62674	1.42208	1.42102
60	0.05	0.0417	0.033	0.03296
216		0.94612	0.74864	0.74767
373		1.53731	1.21643	1.21486
530		1.87241	1.48158	1.47967
686		2.32741	1.64874	1.64662
843		2.22823	1.76313	1.76085
1000		2.33315	1.84615	1.84377
60	0.10	0.01078	0.00772	0.00771
216		0.92407	0.66184	0.66062
373		1.84613	1.32223	1.31979
530		2.44543	1.75145	1.74823
686		3.3346	2.03981	2.03606
843		3.13385	2.24451	2.24038
1000		3.34631	2.39668	2.39227
60	0.15	0.00279	0.00181	0.0018
216		0.90254	0.5851	0.5837
373		2.21699	1.43723	1.4338
530		3.19381	2.07048	2.06554
686		4.77763	2.52364	2.51761
843		4.40754	2.85733	2.8505
1000		4.79944	3.11139	3.10395
60	0.20	0.00072	0.00042	0.00042
216		0.88151	0.51726	0.51574
373		2.66234	1.56223	1.55764
530		4.17122	2.44763	2.44044
686		6.84514	3.12223	3.11306
843		6.19891	3.63745	3.62677
1000		6.8836	4.03922	4.02736
60	0.25	0.00019	0.0001	0.0001
216		0.86097	0.45729	0.45569
373		3.19715	1.69811	1.69219
530		5.44776	2.89347	2.88338
686		9.80736	3.8628	3.84933
843		8.71834	4.63058	4.61444
1000		9.87279	5.24374	5.22546

Table 8: K-Values for C_2-C_4

Temp. °F	X_{N2}	K-Values at 2000 psia	3000 psia	4000 psia
		Table 9: K-Values for C_5-C_6		
60	0.00	0.00167	0.00174	0.00197
216		0.2035	0.21248	0.24001
373		0.40127	0.41896	0.47324
530		0.52621	0.54941	0.62059
686		0.60883	0.63568	0.71804
843		0.66691	0.69631	0.78653
1000		0.70979	0.74109	0.8371
60	0.05	0.000478	0.000503	0.000582
216		0.14909	0.15698	0.18159
373		0.33569	0.35346	0.40887
530		0.46416	0.48873	0.56535
686		0.55256	0.58181	0.67303
843		0.61614	0.64876	0.75047
1000		0.6638	0.69894	0.80851
60	0.10	0.000137	0.000145	0.000172
216		0.10923	0.11598	0.1374
373		0.28082	0.29819	0.35325
530		0.40942	0.43474	0.51502
686		0.50149	0.53251	0.63084
843		0.56924	0.60445	0.71606
1000		0.62079	0.65918	0.7809
60	0.15	3.92E-05	4.2E-05	5.1E-05
216		0.08002	0.08569	0.10396
373		0.23493	0.25157	0.3052
530		0.36114	0.38673	0.46917
686		0.45515	0.48739	0.5913
843		0.52592	0.56317	0.68324
1000		0.58056	0.62169	0.75423
60	0.20	1.12E-05	1.21E-05	1.51E-05
216		0.05862	0.06331	0.07866
373		0.19653	0.21224	0.26369
530		0.31855	0.34401	0.42741
686		0.41308	0.44609	0.55423
843		0.48588	0.52471	0.65191
1000		0.54294	0.58633	0.72847
60	0.25	3.22E-06	3.51E-06	4.46E-06
216		0.04295	0.04677	0.05951
373		0.16441	0.17905	0.22782
530		0.28099	0.30601	0.38936
686		0.3749	0.40829	0.51949
843		0.4489	0.48888	0.62203
1000		0.50776	0.55298	0.70359

Temp. °F	X_{N2}	K-Values at 2000 psia	3000 psia	4000 psia

Table 10: K-Values for C_7-C_{11}

Temp. °F	X_{N2}	2000 psia	3000 psia	4000 psia
60	0.00	1.05E-11	1.26E-11	1.53E-11
216		0.03791	0.04543	0.05524
373		0.11775	0.14113	0.1716
530		0.17641	0.21143	0.25709
686		0.21709	0.26018	0.31636
843		0.2463	0.29519	0.35893
1000		0.26812	0.32134	0.39073
60	0.05	2.21E-13	2.72E-13	3.41E-13
216		0.02299	0.02833	0.03549
373		0.08493	0.10465	0.1311
530		0.13535	0.16676	0.20892
686		0.17191	0.21182	0.26536
843		0.19884	0.245	0.30693
1000		0.21929	0.27019	0.33849
60	0.10	4.65E-15	5.89E-15	7.6E-15
216		0.01395	0.01767	0.02281
373		0.06126	0.0776	0.10016
530		0.10384	0.13153	0.16978
686		0.13614	0.17245	0.22259
843		0.16053	0.20334	0.26247
1000		0.17935	0.22718	0.29323
60	0.15	9.78E-17	1.27E-16	1.69E-16
216		0.00846	0.01102	0.01465
373		0.04419	0.05754	0.07652
530		0.07967	0.10374	0.13797
686		0.10781	0.14039	0.18671
843		0.1296	0.16877	0.22444
1000		0.14669	0.19101	0.25403
60	0.20	2.06E-18	2.75E-18	3.77E-18
216		0.00513	0.00687	0.00942
373		0.03187	0.04267	0.05846
530		0.06112	0.08183	0.11212
686		0.08538	0.1143	0.15661
843		0.10463	0.14007	0.19193
1000		0.11997	0.1606	0.22006
60	0.25	4.33E-20	5.96E-20	8.41E-20
216		0.00311	0.00429	0.00605
373		0.02299	0.03164	0.04466
530		0.0469	0.06454	0.09111
686		0.06761	0.09305	0.13137
843		0.08447	0.11626	0.16413
1000		0.09812	0.13504	0.19064

Temp. °F	X_{N2}	K-Values at		
		2000 psia	3000 psia	4000 psia
60	0.00	8.52E-12	1.28E-11	1.7E-11
216		0.001325	0.001987	0.002649
373		0.008499	0.012749	0.016998
530		0.01718	0.025769	0.034359
686		0.024874	0.037312	0.049749
843		0.031253	0.04688	0.06250603
1000		0.036488	0.054732	0.07297534
60	0.05	3.34E-13	5.27E-13	7.29E-13
216		0.000571	0.000901	0.00125
373		0.00464	0.00732	0.0101
530		0.01025	0.01619	0.02239
686		0.01555	0.02457	0.03397
843		0.02012	0.03177	0.04394
1000		0.02396	0.03783	0.05232
60	0.10	1.31E-14	2.18E-14	3.12E-14
216		0.000246	0.000409	0.000586
373		0.00253	0.00421	0.00603
530		0.00611	0.0102	0.0146
686		0.00973	0.0162	0.0232
843		0.01295	0.02154	0.03089
1000		0.01573	0.02615	0.03752
60	0.15	5.13E-16	8.98E-16	1.34E-15
216		0.000106	0.000185	0.000276
373		0.00138	0.00242	0.00359
530		0.00365	0.00639	0.0095
686		0.00608	0.0106	0.0158
843		0.00834	0.0146	0.0217
1000		0.0103	0.0181	0.0269
60	0.20	2.01E-17	3.7E-17	5.72E-17
216		4.56E-05	8.41E-05	0.00013
373		0.000753	0.00139	0.00214
530		0.00218	0.00401	0.00619
686		0.0038	0.00701	0.0108
843		0.00537	0.00989	0.0153
1000		0.00678	0.0125	0.0193
60	0.25	7.87E-19	1.53E-18	2.45E-18
216		1.96E-05	3.81E-05	6.1E-05
373		0.000411	0.000797	0.00128
530		0.0013	0.00252	0.00403
686		0.00238	0.00462	0.00739
843		0.00345	0.00671	0.0107
1000		0.00445	0.00864	0.0138

Table 11: K-Values for C_{12}-C_{17}

Table 12: K-Values for C_{18+}				
Temp. °F	X_{N2}	K-Values at		
		2000 psia	3000 psia	4000 psia
60	0.00	3.94E-17	1.33E-16	2.13E-16
216		1.32E-05	4.49E-05	7.15E-05
373		0.000198	0.000672	0.00107
530		0.000554	0.00188	0.00299
686		0.000954	0.00323	0.00515
843		0.00133	0.00452	0.0072
1000		0.00167	0.00567	0.00903
60	0.05	6.33E-19	2.45E-18	4.11E-18
216		3.88E-06	1.5E-05	2.52E-05
373		7.8E-05	0.000302	0.000506
530		0.000244	0.000946	0.00159
686		0.000446	0.00173	0.00289
843		0.000646	0.0025	0.0042
1000		0.000831	0.00322	0.0054
60	0.10	1.02E-20	4.5E-20	7.94E-20
216		1.13E-06	5.02E-06	8.86E-06
373		3.07E-05	0.000136	0.00024
530		0.000108	0.000476	0.00084
686		0.000208	0.000922	0.00163
843		0.000313	0.00139	0.00245
1000		0.000413	0.00183	0.00323
60	0.15	1.63E-22	8.26E-22	1.53E-21
216		3.32E-07	1.68E-06	3.12E-06
373		1.21E-05	6.11E-05	0.000113
530		4.74E-05	0.00024	0.000445
686		9.74E-05	0.000492	0.000914
843		0.000152	0.000768	0.00143
1000		0.000205	0.00104	0.00193
60	0.20	2.63E-24	1.52E-23	2.96E-23
216		9.73E-08	5.62E-07	1.1E-06
373		4.76E-06	2.75E-05	5.37E-05
530		2.09E-05	0.000121	0.000236
686		4.55E-05	0.000263	0.000514
843		7.36E-05	0.000425	0.000831
1000		0.000102	0.00059	0.00115
60	0.25	4.22E-26	2.79E-25	5.73E-25
216		2.85E-08	1.88E-07	3.87E-07
373		1.87E-06	1.24E-05	2.54E-05
530		9.19E-06	6.07E-05	0.000125
686		2.13E-05	0.00014	0.000289
843		3.57E-05	0.000236	0.000485
1000		5.07E-05	0.000335	0.000689

Table 15: Composition of initial oil used in coreflood tests.	
Component	Mole Fraction
N_2	0.010300
C_1	0.427600
CO_2	0.004800
C_2-C_4	0.053900
C_5-C_6	0.019500
C_7-C_{11}	0.159188
C_{12}-C_{17}	0.148904
C_{18+}	0.175808

3.5   Simulation Results

Figures 2 through 9 show the simulation results versus the experimental data. For both runs the effluent global mole fractions compare well with the experimental data and, although not compared here, are in excellent agreement with Fassihi's EOS simulations of the experiments. This indicates that the composition dependent k-value tables employed successfully captured the vaporization phenomena.

It is important to mention here that these history matches were obtained with the STARS "SXY" formulation. Although no water was present in the experiments a very minute quantity had to be incorporated in the model because the "SXY" formulation uses the water mole balance to solve for pressure. The STARS "ZT" formulation which does not require a water phase to be present was also tried without success. The failure was due to a "bug" that existed in STARS at the time these simulations were performed.

Figure 2: Simulation vs. Exp. Data, coreflood at 3500 psia.
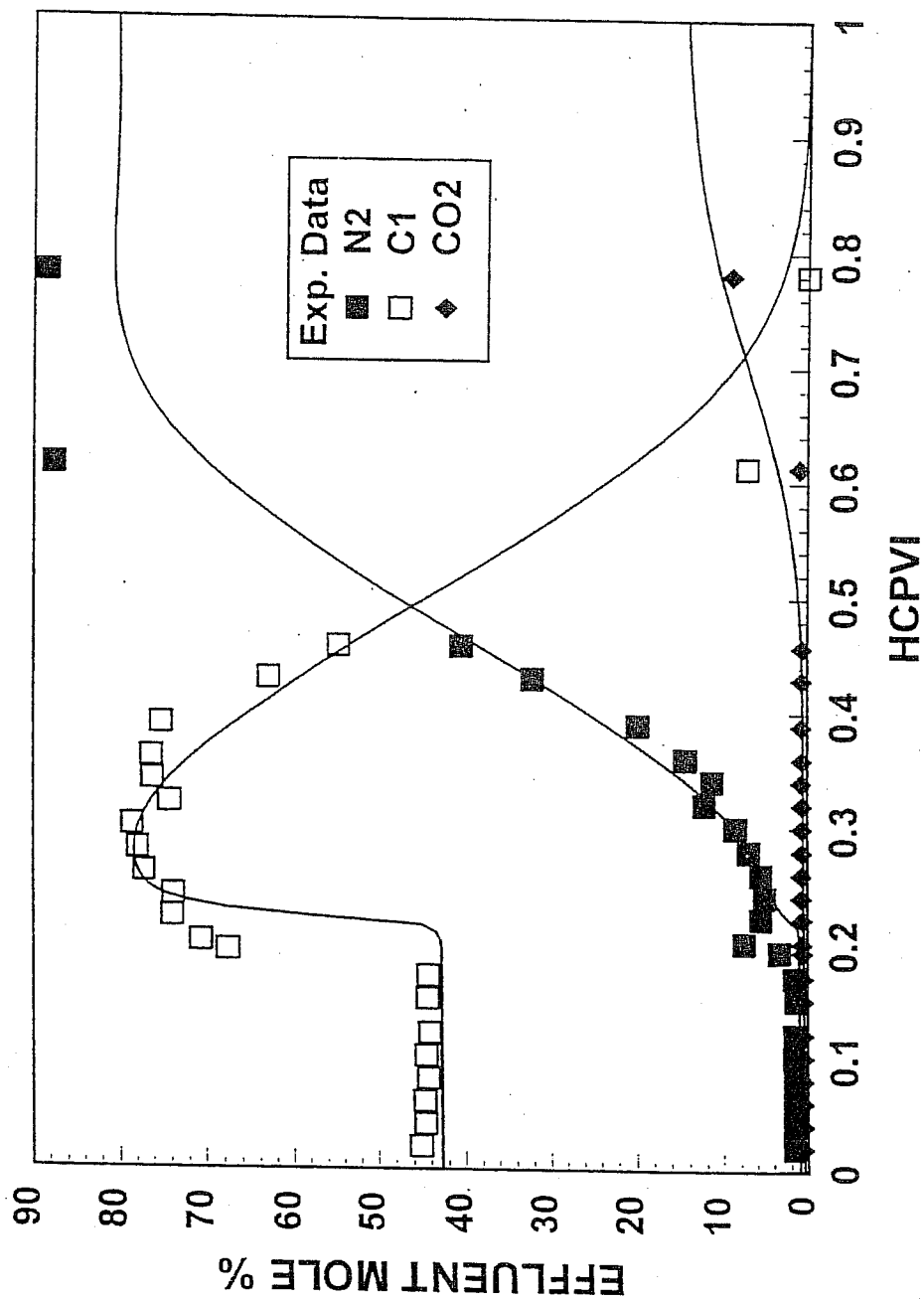
Figure 3: Simulation vs. Exp. Data coreflood at 3500 psia
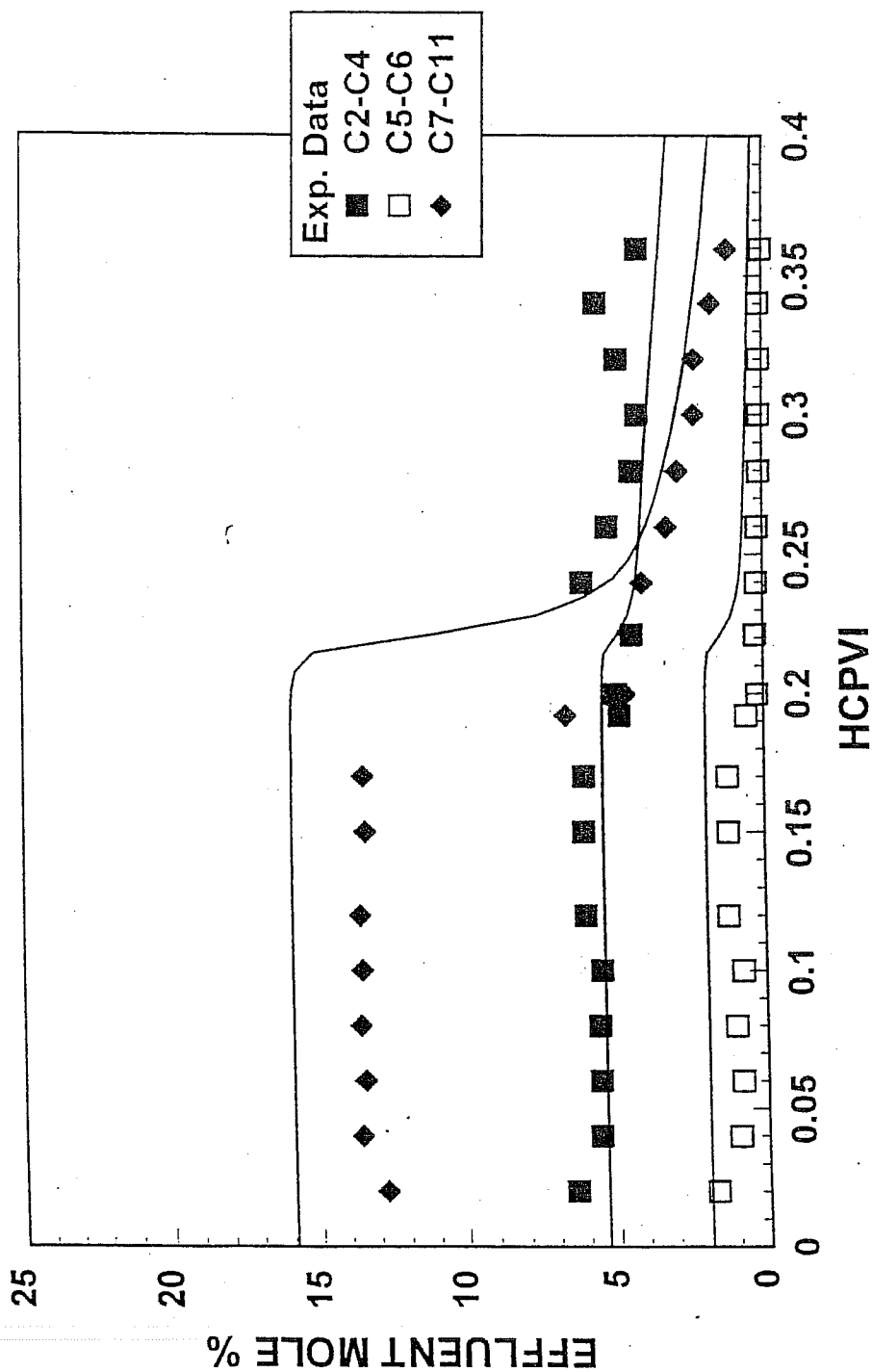
Figure 4: Simulation vs. Exp. Data coreflood at 3500 psia
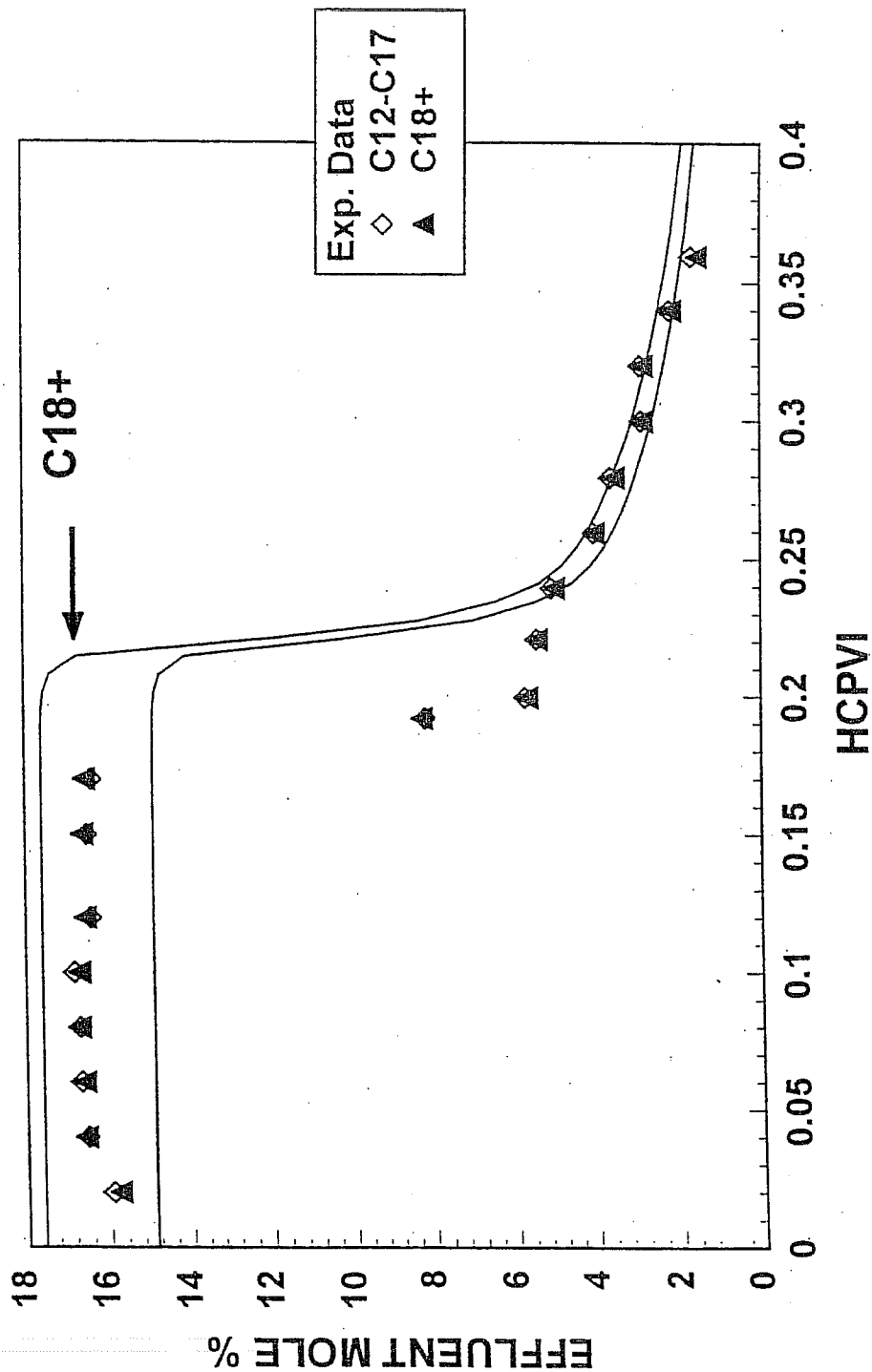
Figure 5: Simulation vs. Exp. Data coreflood at 3500 psia
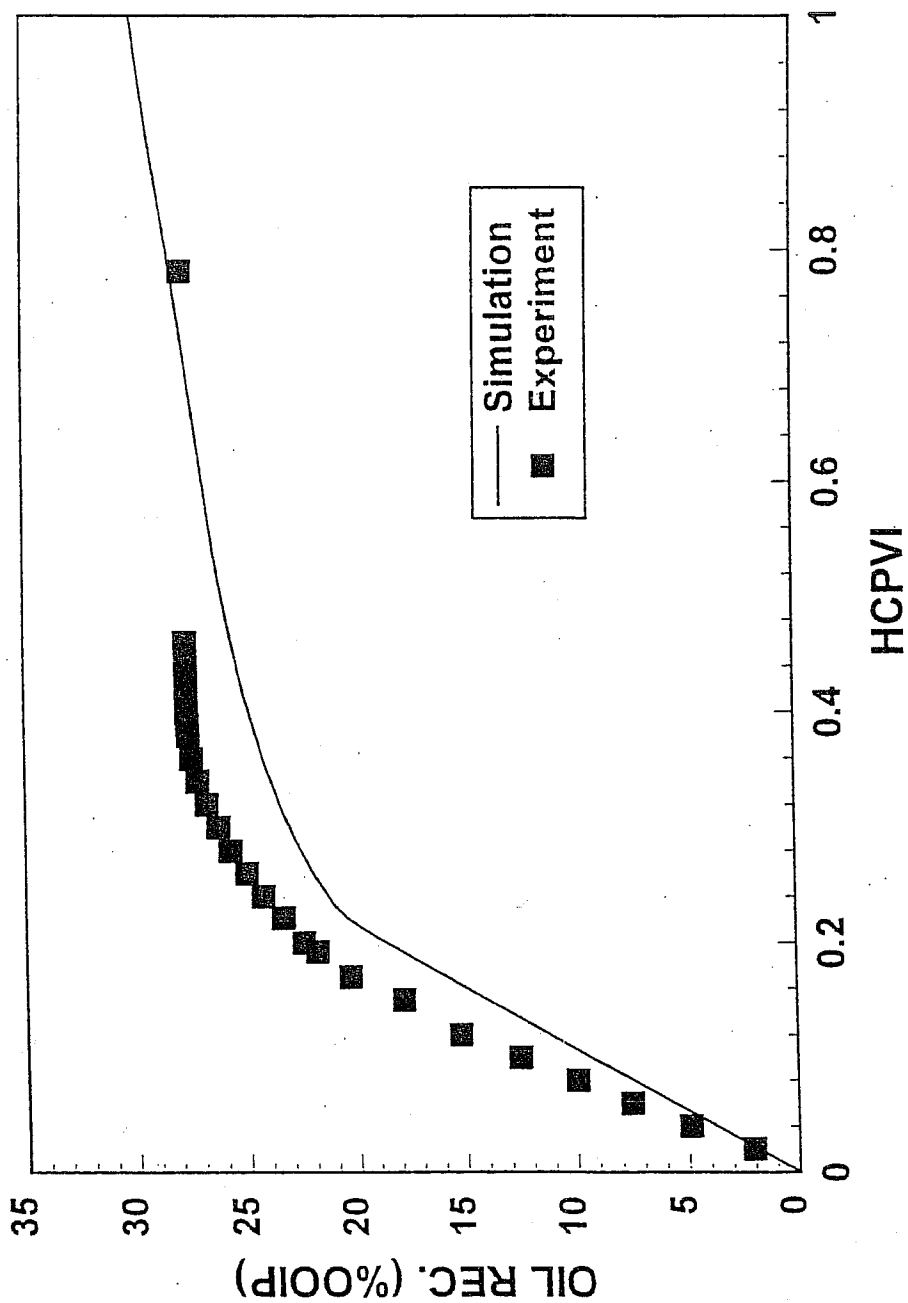
Figure 6: Simulation vs. Exp. Data cooreflood at 2200 psia
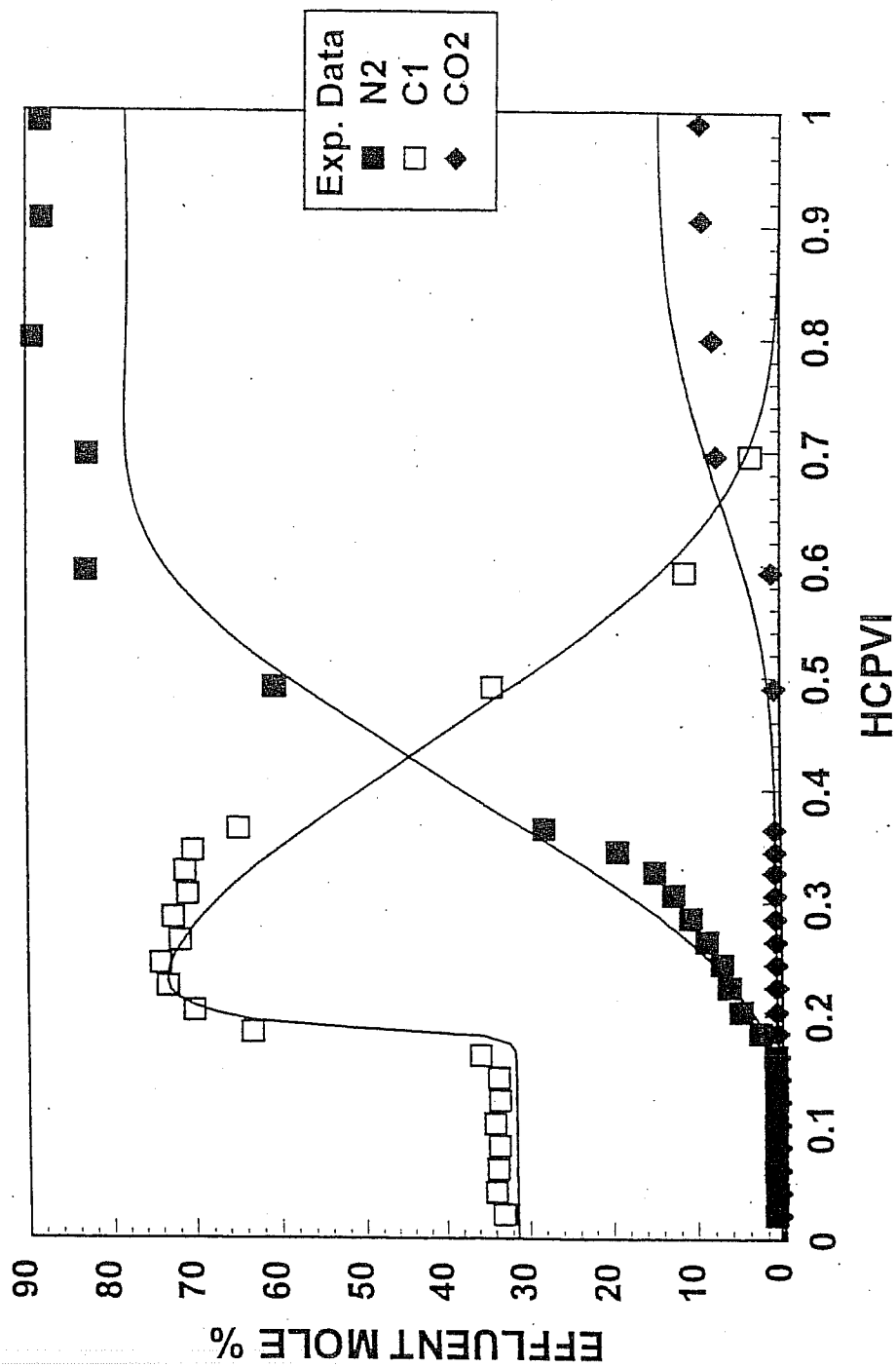
Figure 7: Simulation vs. Exp. Data coreflood at 2200 psia
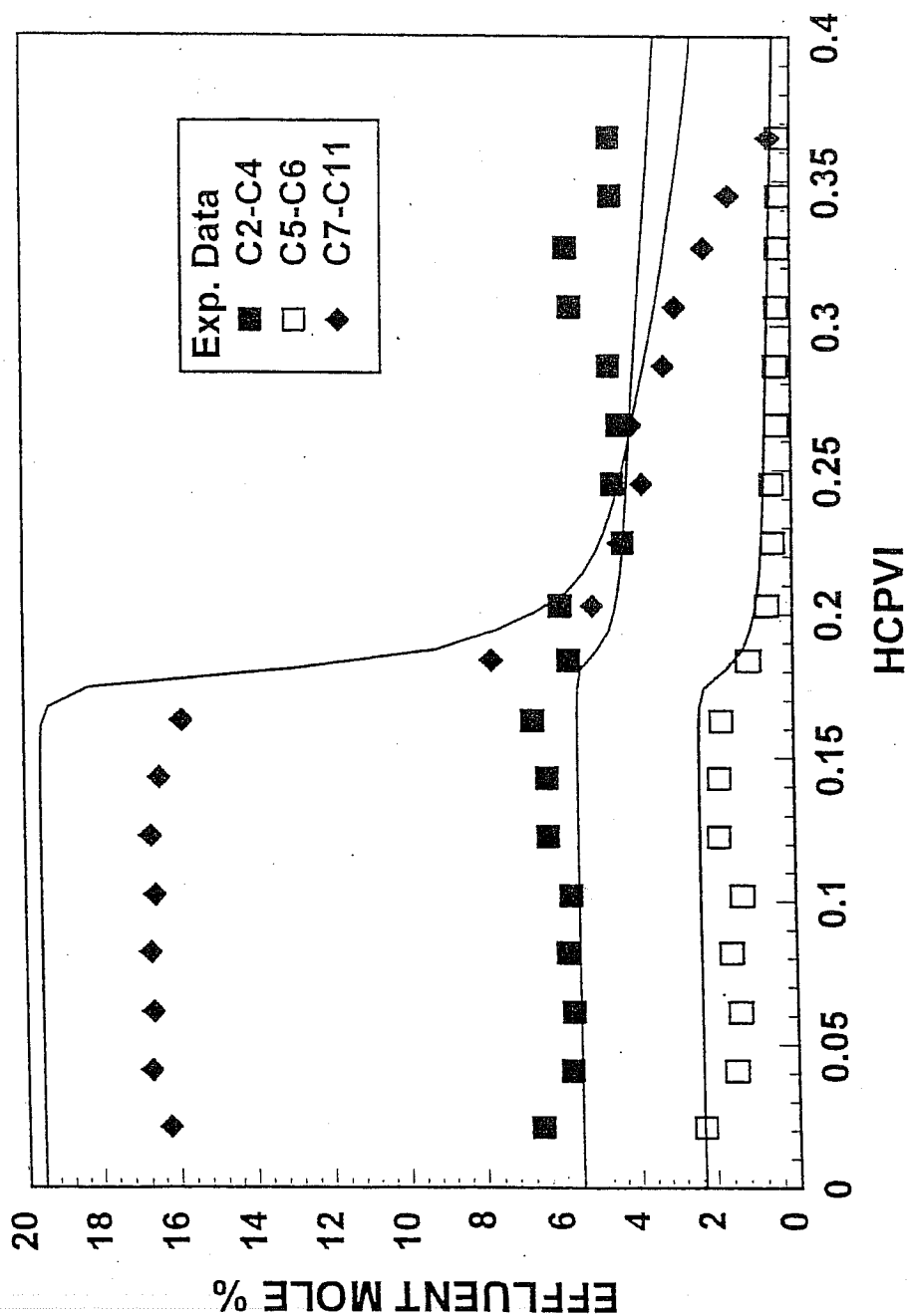
Figure 8: Simulation vs. Exp. Data coreflood at 2200 psia

C18+

Exp. Data
◇ C12-C17
▲ C18+

HCPVI

EFFLUENT MOLE %
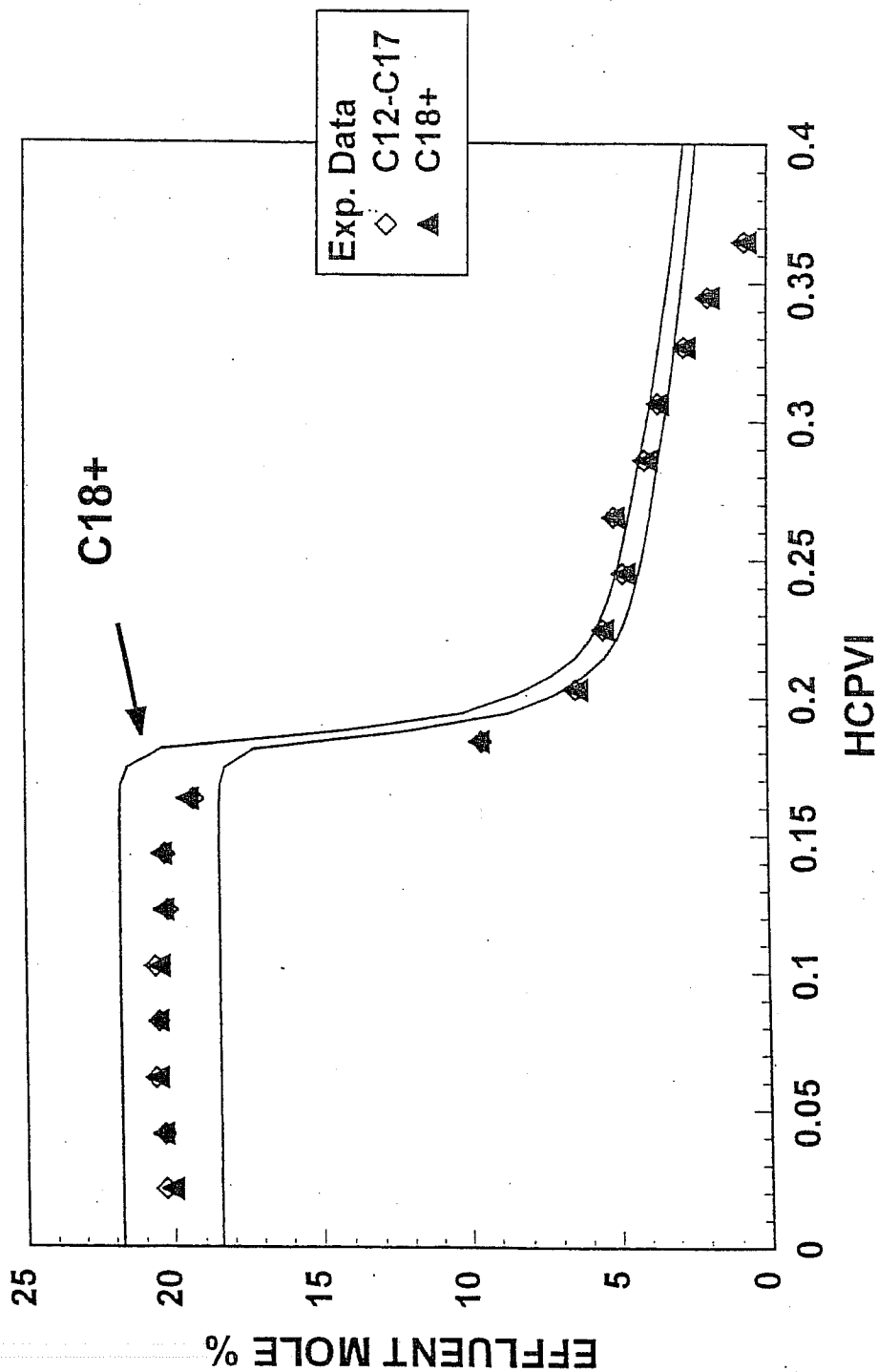
Figure 9: Simulation vs. Exp. Data coreflood at 2200 psia
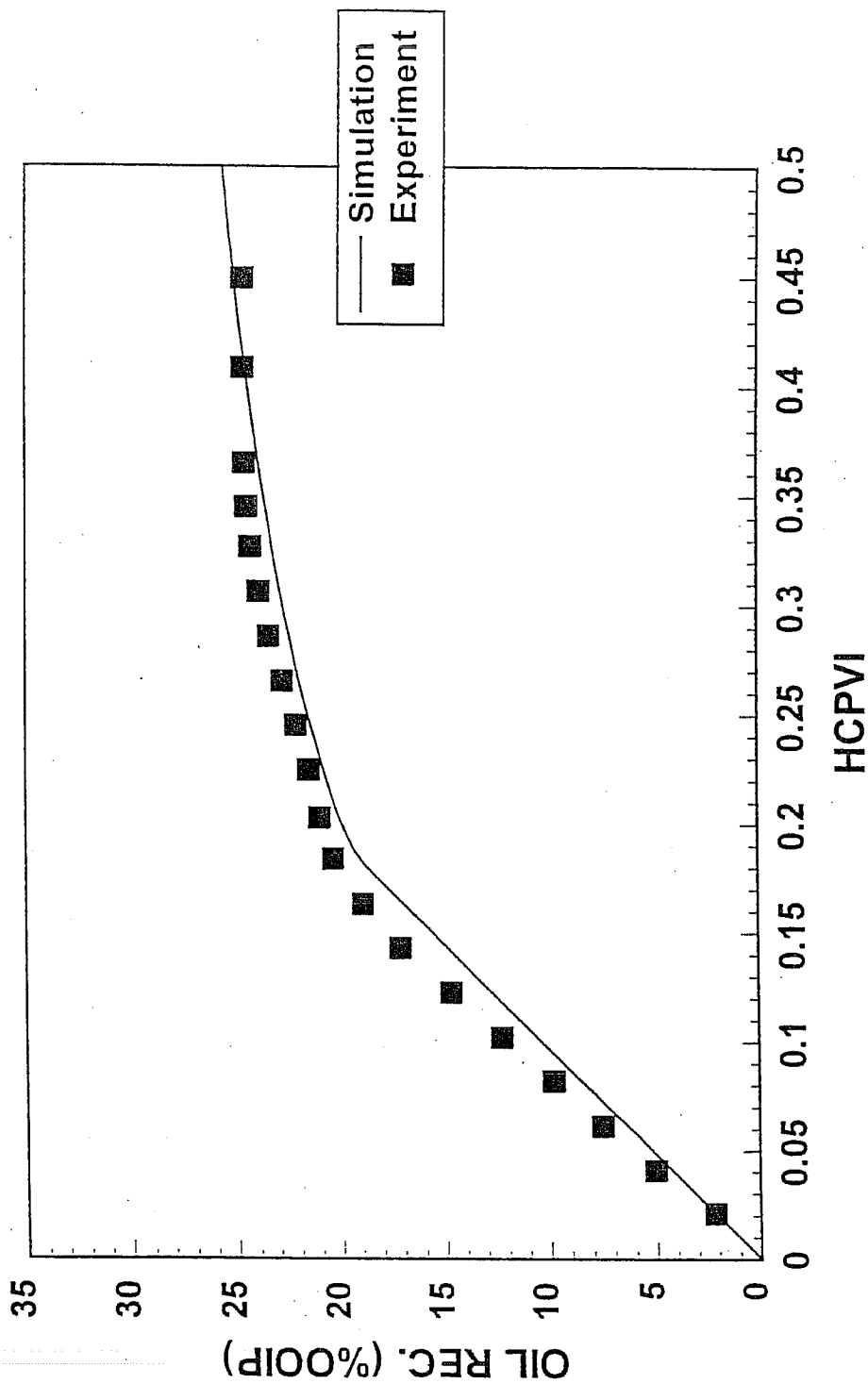
4.0 REACTION MODEL FOR AIR INJECTION

Every effort was made to reconcile the Accelerating Rate Calorimeter (ARC) data and the combustion tube data to arrive at a consistent reaction scheme for the oxidation of theWest Hackberry oil.

4.1 Kinetic Parameters from ARC Data

Amoco's mathematical fit of the ARC experimental data for West Hackberry oil (Amoco Test ID# 26209, conducted in the presence of sand) produced an order of reaction with respect to the oil concentration of 0.3, an activation energy of 48600 Btu/lbmol, and an Arrhenius frequency (or pre-exponential) factor of 1.6 E+10 sec^{-1}. The quantities were used as an initial basis for specifying the oxidation reaction kinetics.

4.2 Reaction Stoichiometry from Combustion Tube Data

From the combustion tube data it is possible to specify the stoichiometry of the oxidation reactions. The air requirement for the air injection experiment conducted at 2000 psia (run HB2) was experimentally determined to be 184 SCF air per lb fuel. Assuming 21% oxygen in the injected air, then 38.64 SCF of oxygen burns 1 lb of fuel (hydrocarbon). From the ideal gas law the mass of 38.64 SCF of oxygen is calculated as

$$m = \frac{PV}{RT} = \frac{(14.7 \text{ psia})(38.64 \text{ SCF}))}{\left(\dfrac{10.731}{32}\right)(520\,^{\circ}R)} \tag{5}$$

$$= 3.257 \text{ lb } O_2$$

From the K-value description of the oil, the hydrocarbon pseudo components C_1 to C_{5-6} were found to be too volatile to exist in the liquid phase at temperatures approaching that of the reaction zone. Thus the C_7-C_{11}, C_{12}-C_{17}, and C_{18+} fractions were the only oil components specified for liquid phase oxidation.

Since 1 lb of hydrocarbon reacts with 3.257 lbs of oxygen, then as an example, for the oxidation of C_{18+} with a molecular mass of 190.56 we have on a molar basis

$$\frac{1}{190.56} \text{ moles } C_{12}\text{-}C_{17} + \frac{3.257}{32} \text{ moles } O_2 - \alpha' \, CO_2 + \beta' \, H_2O$$

or, on a per mole of fuel basis,

$$C_{7.} + 19.395 \, O_2 \; - \; \alpha \, CO_2 + \beta \, H_2O \tag{6}$$

From the experimental results,
21.0% O_2 in the air stream is replaced approximately by (averaged over runs HB2 and HB3)

      13.1% $CO_2 + CO$
      2.5% O_2

in the product gas stream. Thus 18.5% O_2 in the injected air is converted to 13.1% CO_x in the produced gases.

Now, assuming
     (I)   ideal gas behaviour,
     (ii)   equimolar replacement of reacted oxygen with carbon oxides, and
     (iii) CO_x is composed essentially of CO_2 , then

     18.5 moles of O_2 produces 13.1 moles of CO_2

Therefore α in Eq. 6 is calculated as

$$\alpha = \frac{(13.1)(19.395)}{(18.5)}$$

$$= 13.734$$

The stoichiometric coefficient β for the production of water in Eq. 6 is now determined from the reaction material balance which is expressed as

$$\left\{ \sum s_i \, MW_i \right\}_{reactants} = \left\{ \sum s_i \, MW_i \right\}_{products} \tag{7}$$

where
     s_i =   stoichiometric coefficient
     MW_i =   molar mass of the ith reactant (or product}

Thus from Eq. 7 , β is calculated as

$$\beta = \frac{\lfloor (190.56)(1) + (19.395)(32) \rfloor - \lfloor (13.734)(44.01) \rfloor}{18.0}$$

$$= 11.488$$

This procedure was used to also specify the stoichiometry for the oxidation of C_7-C_{11} and C_{18+}. Thus, the liquid phase oxidation of the oil is to a large degree defined by the ARC and combustion tube data. This treatment outlined above is considered to be the first step in determining an appropriate reaction scheme for history matching the combustion tube experiment.

4.3   Reaction Scheme Employed in History Match

Six reactions were specified in history matching the combustion tube experiment:

Reaction #1 (cracking):
    C_{12}-$C_{17} \rightarrow 0.6663$ Coke $+ 1.5276\ C_7$-C_{11}

Frequency factor	$= 3.3521 \times 10^{10}$ hr^{-1}
Activation energy	$= 77435$ Btu/lbmol
Order of reaction[1] with respect to reactants	$= 1.0$
Reaction enthalpy	$= 0.0$

Reaction #2 (cracking):
    $C_{18+} \rightarrow 1.255$ Coke $+ 2.8774\ C_7$-C_{11}

Frequency factor	$= 3.3521 \times 10^{10}$ hr^{-1}
Activation energy	$= 77435$ Btu/lbmol
Order of reaction with respect to reactants	$= 1.0$
Reaction enthalpy	$= 0.0$
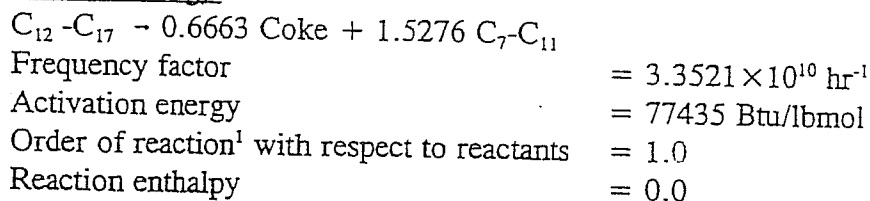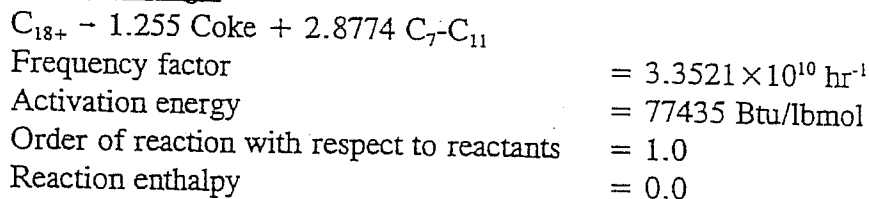
Reaction #3 (liquid phase oxidation):
    C_7-$C_{11} + 12.062\ O_2 \rightarrow 8.541\ CO_2 + 7.145\ H_2O$

Frequency factor	$= 4.0 \times 10^{10}$ hr^{-1} psi^{-2}
Activation energy	$= 48600$ Btu/lbmol
Order of reaction with respect to reactants	$= 2.0$ for C_7-C_{11} ; 1.0 for O_2
Reaction enthalpy	$= 100$ kcal/gmol O_2 for run HB2
	$= 60$ kcal/gmol O_2 for run HB3

---
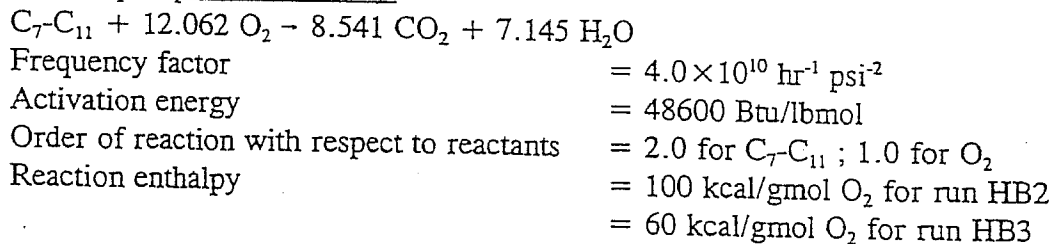
[1]The order of reaction in the case of oxygen as reaction is with respect to its partial pressure in the gaseous phase. All other reactants have their reaction orders specified with respect to their molar concentrations in the grid block.

Reaction #4 (liquid phase oxidation):
    $C_{12}-C_{17} + 19.395\ O_2 \rightarrow 13.734\ CO_2 + 11.488\ H_2O$
        Frequency factor $= 4.0 \times 10^{10}\ hr^{-1}\ psi^{-2}$
        Activation energy $= 48600\ Btu/lbmol$
        Order of reaction with respect to reactants $= 2.0\ for\ C_{12}-C_{17}\ ;\ 1.0\ for\ O_2$
        Reaction enthalpy $= 100\ kcal/gmol\ O_2\ for\ run\ HB2$
                                                             $= 60\ kcal/gmol\ O_2\ for\ run\ HB3$

Reaction #5 (liquid phase oxidation):
    $C_{18+} + 36.535\ O_2 \rightarrow 25.871\ CO_2 + 21.639\ H_2O$
        Frequency factor $= 4.0 \times 10^{10}\ hr^{-1}\ psi^{-2}$
        Activation energy $= 48600\ Btu/lbmol$
        Order of reaction with respect to reactants $= 2.0\ for\ C_7-C_{11}\ ;\ 1.0\ for\ O_2$
        Reaction enthalpy $= 100\ kcal/gmol\ O_2\ for\ run\ HB2$
                                                             $= 60\ kcal/gmol\ O_2\ for\ run\ HB3$

Reaction #6 (coke burning):
    $Coke + 1.455\ O_2 \rightarrow 1.0\ CO_2 + 0.0.9366\ H_2O$
        Frequency factor $= 1.0 \times 10^8\ hr^{-1}\ psi^{-1}$
        Activation energy $= 14967\ Btu/lbmol$
        Order of reaction with respect to reactants $= 1.0\ for\ both\ reactants$
        Reaction enthalpy $= 100\ kcal/gmol\ O_2$

Reactions #1 and #2 were essentially specified as a means of controlling the amount of liquid phase that was available for oxidation (in addition to adjusting the residual oil saturation to gas). The kinetic parameters for this reaction were obtained from the University of Calgary combustion database for an oil with similar gravity. As it turned out this reaction played a very minimal (if not an imperceptible) role in the history matching process because of the high activation energy. Thus the amount of coke formed was also insignificant.

Reactions #3, #4, and #5 are the dominating reactions and are presented in their final optimized form. Note that the reaction order with respect to oil concentration is specified as 2.0. This was necessary to achieve stable computations. It was not possible to run STARS with pratical time step sizes or without crashing using the ARC value of 0.3. For the same reason, the value of the pre-exponential factor also had to be adjusted. The pre-exponental factor was adjusted until stable computations were achieved and as close a match as possible to the effluent oxygen content in the produced gas streams were obtained.

Reaction #6 was specified to consume the coke produced by reactions #1 and #2 and to allow the by-passing of fuel if deemed necessary. Owing to the limited coke formation Reaction #6 hardly influenced the history matching. The stoichiometry of this reaction is based on the

procedure outlined above as well as the lower of the two fuel H/C ratios observed in runs HB2 and HB3 which was 2.3.

The reaction enthalpy of 100 kcal per gmol of oxygen consumed assumes complete conversion of hydrocarbons to carbon oxides and water[3]. This value was used to history match the lower pressure air injection test, run HB2 (conducted at 2000 psia). It is expected that a vertically operated combustion tube test will have higher heat losses at higher operating pressures because of increased convective circulatory gas movement in the annular region between the tube and pressure jacket[4]. Rather than impose heat losses of different magnitudes to history match the two experiments, run HB3 (conducted at 3500 psia) was history matched with a lower reaction enthalpy. The resulting reaction enthalpy for the match in peak temperatures in run HB3 was 60 kcal/gmol of oxygen consumed.

5.0 SIMULATION OF COMBUSTION TUBE AIR INJECTION PERFORMANCE

5.1 Laboratory Combustion Tube and Simulator One-Dimensional Grid

The simulation grid was specified as one-dimensional and having 22 grid blocks, one grid block for each experimental thermocouple/heater zone. This facilitated the direct comparison of calculated and laboratory temperatures, while minimizing the computational overhead.

5.2 Initial Composition of the Combustion Tube Oil

An examination of the composition of the oil used to saturate the combustion tube shows that a substantial amount of the light ends were absent as compared to the live oil (Table 15) used for the flue gas experiments. The composition of this "dead oil" is given in Table 16. This composition was used to initialize the model for both the history matching of the air injection tests.

Table 16 - Composition of combustion tube oil.

N_2	0.00000
C_1	0.00000
CO_2	0.00000
C_2-C_4	0.01030
C_5-C_6	0.03870
C_7-C_{11}	0.30890
C_{12}-C_{17}	0.34630
C_{18+}	0.29580
	1.00000

5.3 History Matching Procedure

At the time of ignition of the combustion tube experiment the oil saturation across the axial length of the core is not uniform. The injection end has been subjected to gas injection to pressurize the tube, vapour stripping of the light components at this end, and elevated temperatures to ignite the core. Thus the injection end of the core will have a lower oil saturation

than in the rest of the tube. Thus this period must be incorporated in the history match.

The initial oil flood to residual water saturation and the tube pressurization/ignition heating stage provides useful information that allows calibration of the relative permeability curves. Tables 17 and 18 are the resulting relative permeability curves based on the history matching of these two phases of the air injection experiments.

Table 17: Oil-Water relative permeability for combustion tube tests.		
S_w	k_{rw}	k_{row}
0.00	0.000	1.000
0.10	0.001	0.729
0.20	0.008	0.512
0.30	0.027	0.343
0.40	0.064	0.216
0.50	0.125	0.125
0.60	0.216	0.064
0.70	0.343	0.027
0.80	0.512	0.008
0.90	0.729	0.001
1.00	1.000	0.000

These relative permeability tables were renormalized internally within STARS to inlcude user specifed residual saturations other than zero. An important note at this point is that the liquid saturation in th gas-liquid relative permeability data was specified in the simulation data sets as **NOT** containing any connate water, i.e S_l contained only oil. This prevents a large oil saturation from being immobilized when water vaporizes completely with a grid block. This technique also facilitates adjustment of the quantity of oil burned by offering direct control of the residual oil saturation to gas. The residual oil saturation to gas used to history match the experiments were 0.15 for run HB2 and 0.08 for run HB3. The STARS data sets for the simulation of air injections runs HB2 and HB3 are given in Appendices B-1 and B-2.

Table 18: Gas-liquid relative permeability for combustion tube tests.		
S_l	k_{rg}	k_{rog}
0.00	1.000	0.000
0.10	0.900	0.001
0.20	0.800	0.008
0.30	0.700	0.027
0.40	0.600	0.064
0.50	0.500	0.125
0.60	0.400	0.216
0.70	0.300	0.343
0.80	0.200	0.512
0.90	0.100	0.729
1.00	0.000	1.000

5.4   Combustion Tube Heat Losses

Belgrave et al. (1990) showed that vertically operated combustion tubes experience radial heat losses that increase with an increase in the operating pressure. The radial heat losses are due to convective circulatory movement of the pressuring gas in the annulus. Indeed, this radial heat loss seems to have significantly influenced the temperature profiles obtained from the experiment HB3. As mentioned previously, the simulations were treated as being adiabatic beyond the ignnition heating phase and heat losses were incorporated directly into the oxidation reaction enthalpy. Considering the fact that a single kinetic reaction model was used to simulate both combustion tube experiments, comparison of the reaction enthalpy extracted from the history matches offers a qualitative measure of the relative heat loss from the sand pack at 3500 psia compared to that at 2000 psia.

5.5   History Matches HB2 and HB3

Figures 10 through 19 compare the water, oil and gas cumulative production, oxygen concentration in the produced gas stream and the combustion tube peak temperatures of the

simulations and experimental data for the two air injection tests.

With respect to the volume of fluids produced, the oil and gas volumes are well predicted. In both instances, the calculated water recovery is accelerated and higher compared with the experimental data (Figures 10 and 14). No capillary pressures were used in the simulations, and it seems that strong water-oil capillary pressures are needed to delay the calculated produced water volumes.

Figures 13 and 18 compare produced oxygen mole fraction in the gas phase. In both figures the trend in the effleunt oxygen concentration has been reproduced, but the calculated produced oxygen is higher than the experimental values. It is possible to produce better history matches of the oxygen breakthrough by increasing the frequency factor of the oxidation reactions. However for this air injection problem, increasing the oxidation rate beyond these optimized values has the effect of reducing the radius of convergence or destabilizing the computations.

Figures 15 and 19 compare the maximum or peak temperature in the sand pack at any time. Except for the combustion temperatures at the ignition end of the tube (high experimental early time values), the peak temperatures are well represented by the model. The high combustion temperatures at the injection end of the core can only be accounted for if heat is considered to have been stored at the entrance region of the equipment during the ignition heating and subsequently transferred to the sandpack. This requires more comprehensive modelling capable of accounting for the thermal energy storage and transport external to the sand pack.

Figure 10: Simulation vs. Exp. Data air injection test at 2000 psia
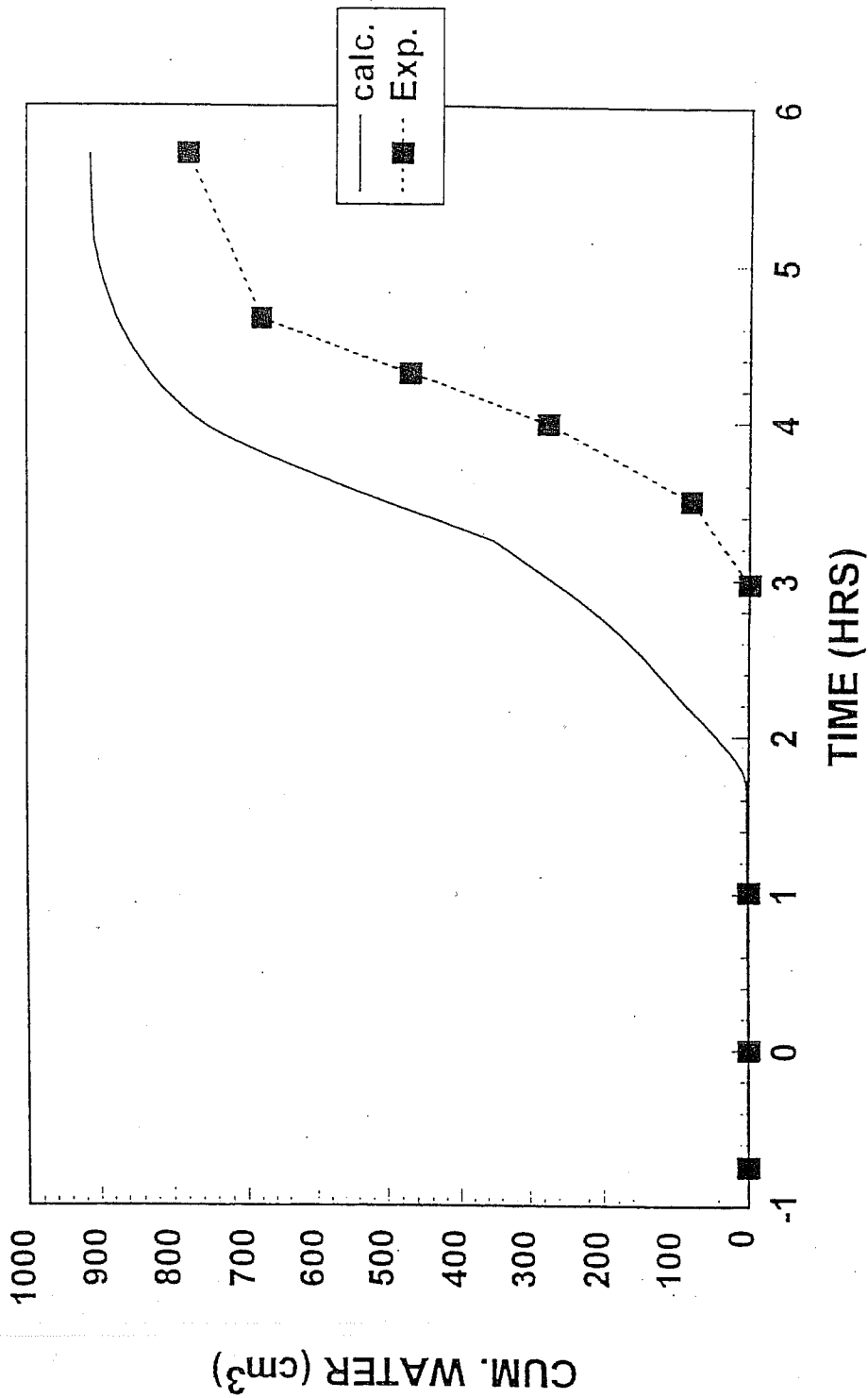
Figure 11: Simulation vs. Exp. Data
air injection test at 2000 psia
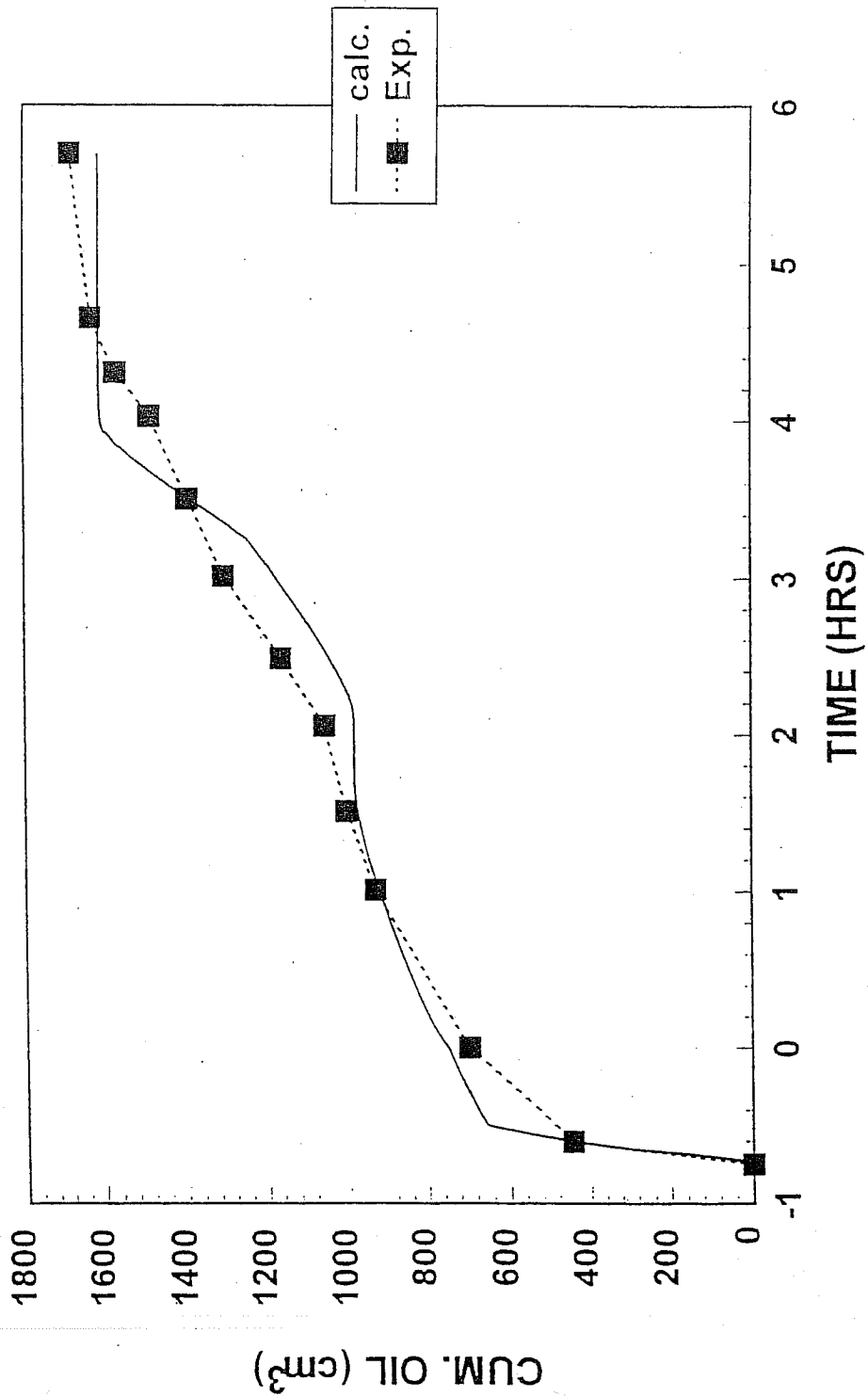
Figure 12: Simulation vs. Exp. Data
air injection test at 2000 psia
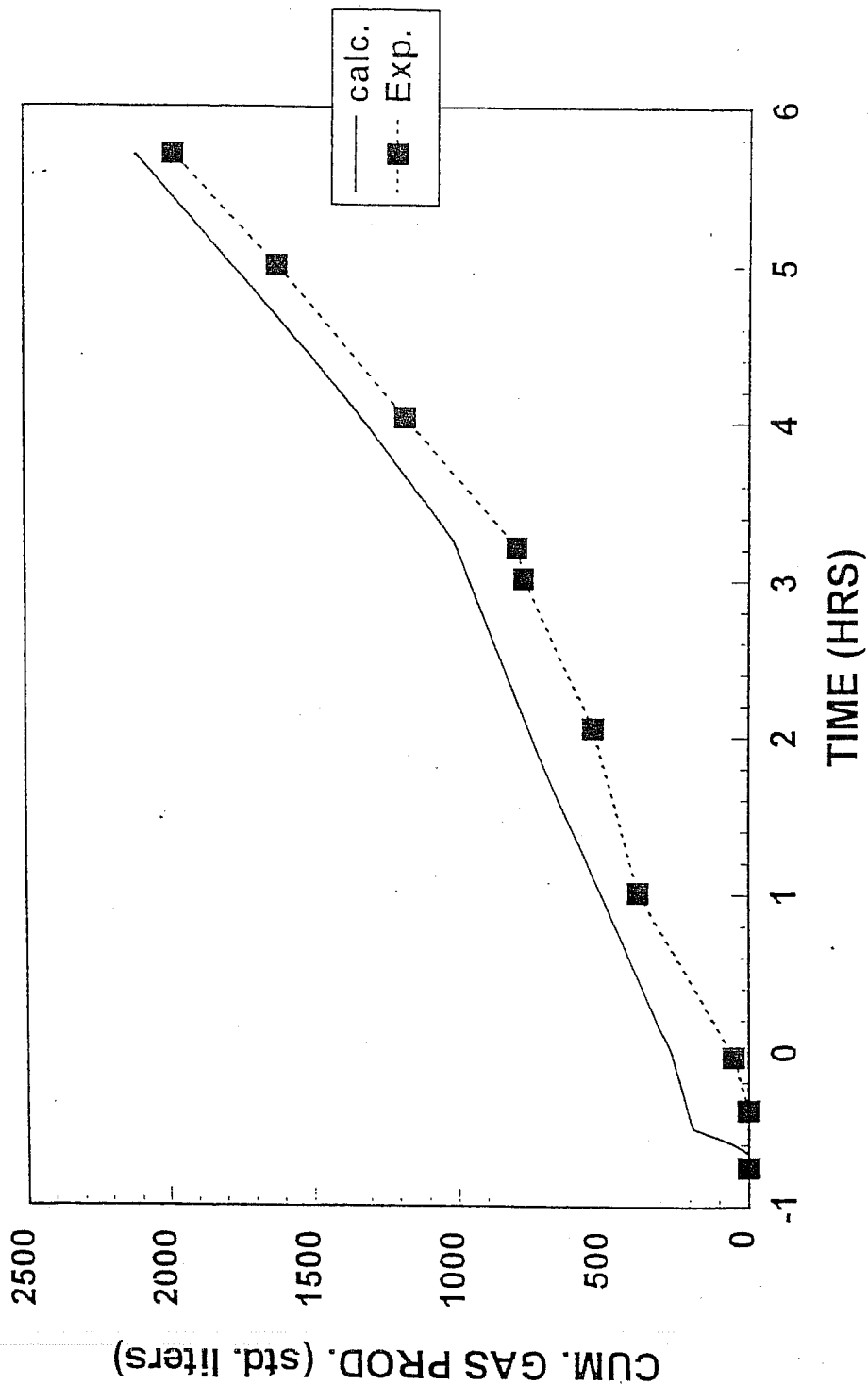
Figure 13: Simulation vs. Exp. Data air injection test at 2000 psia
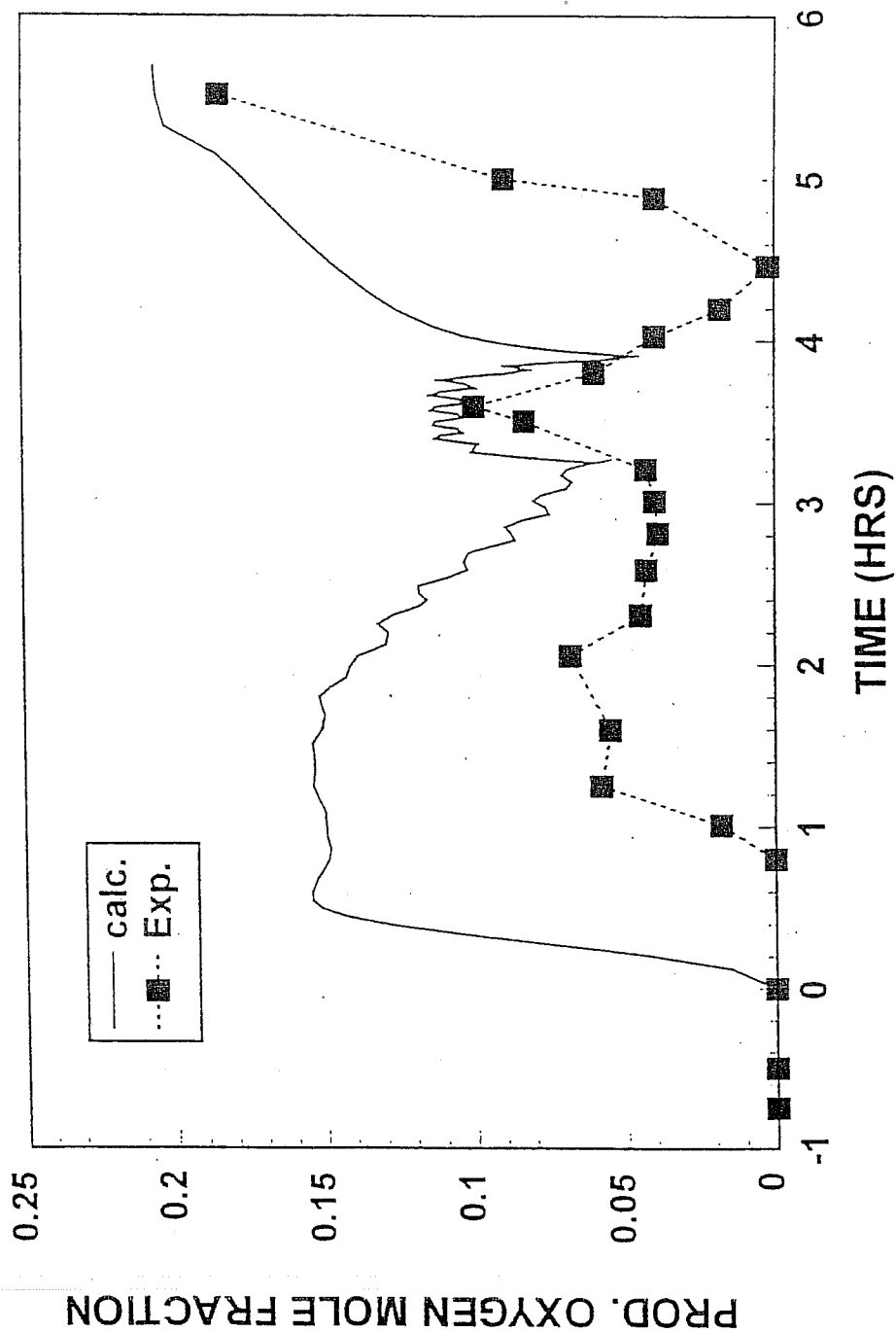
Figure 14: Simulation vs. Exp. Data air injection test at 2000 psia
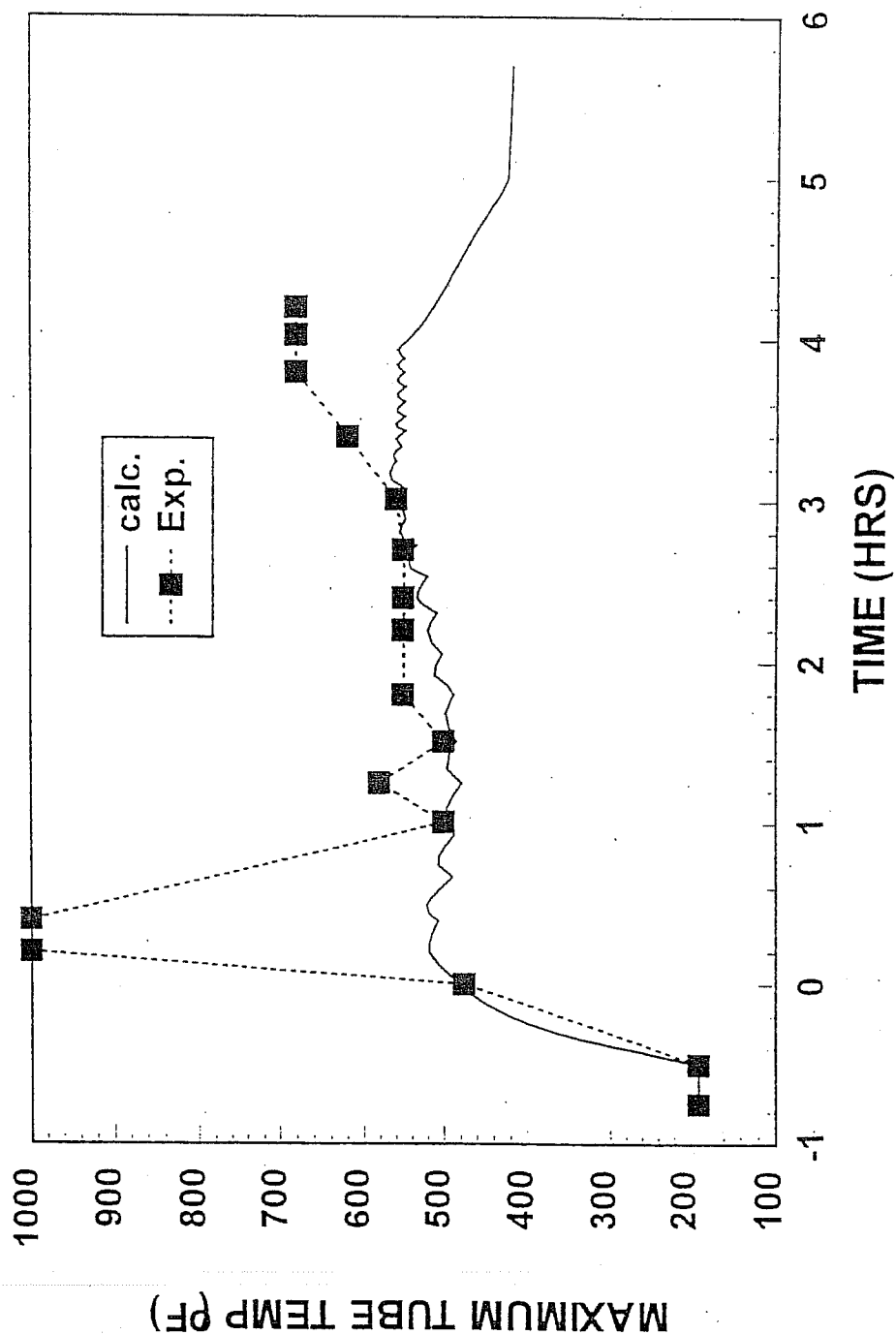
Figure 15: Simulation vs. Exp. Data air injection test at 3500 psia
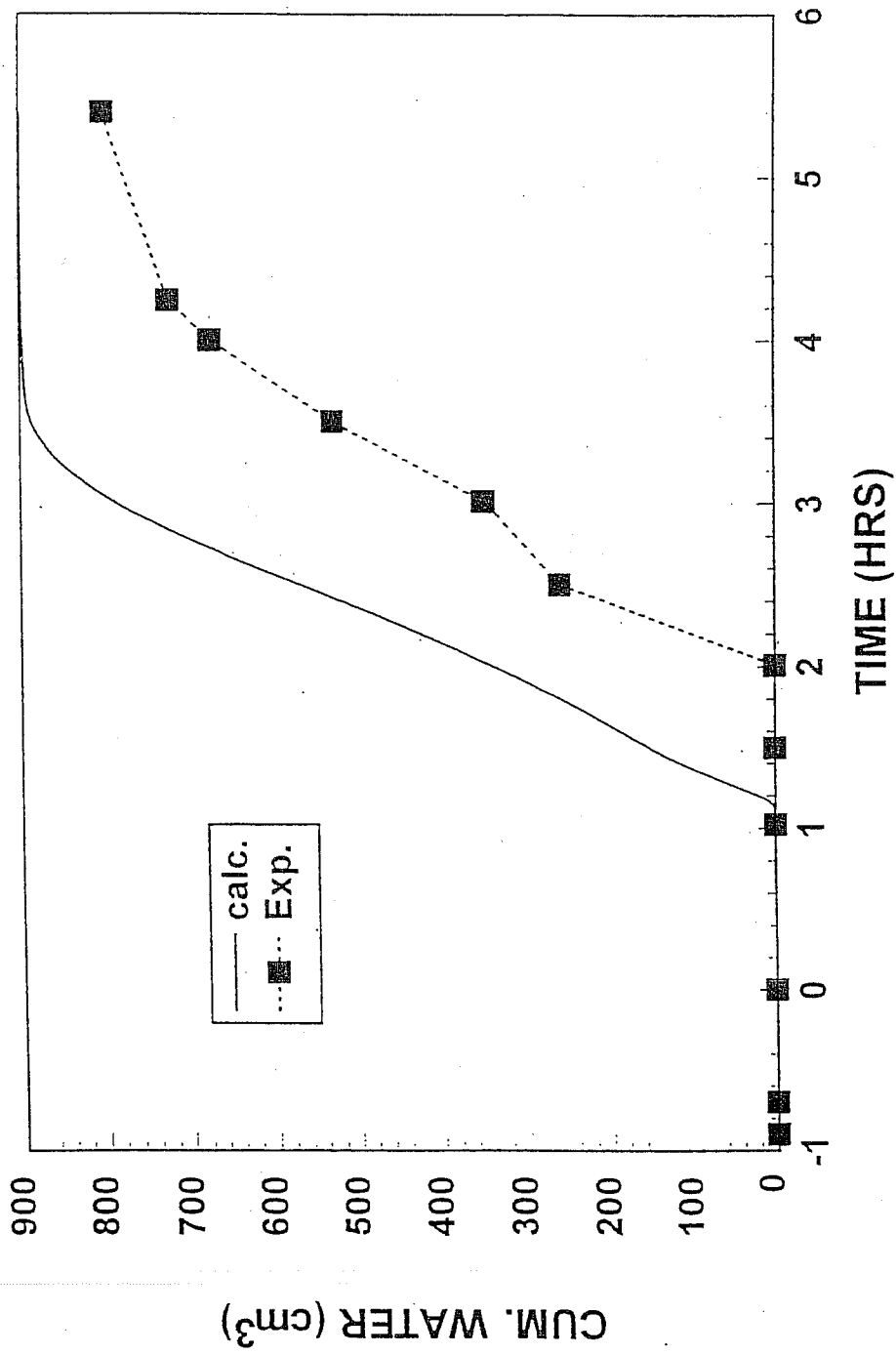
Figure 16: Simulation vs. Exp. Data air injection test at 3500 psia
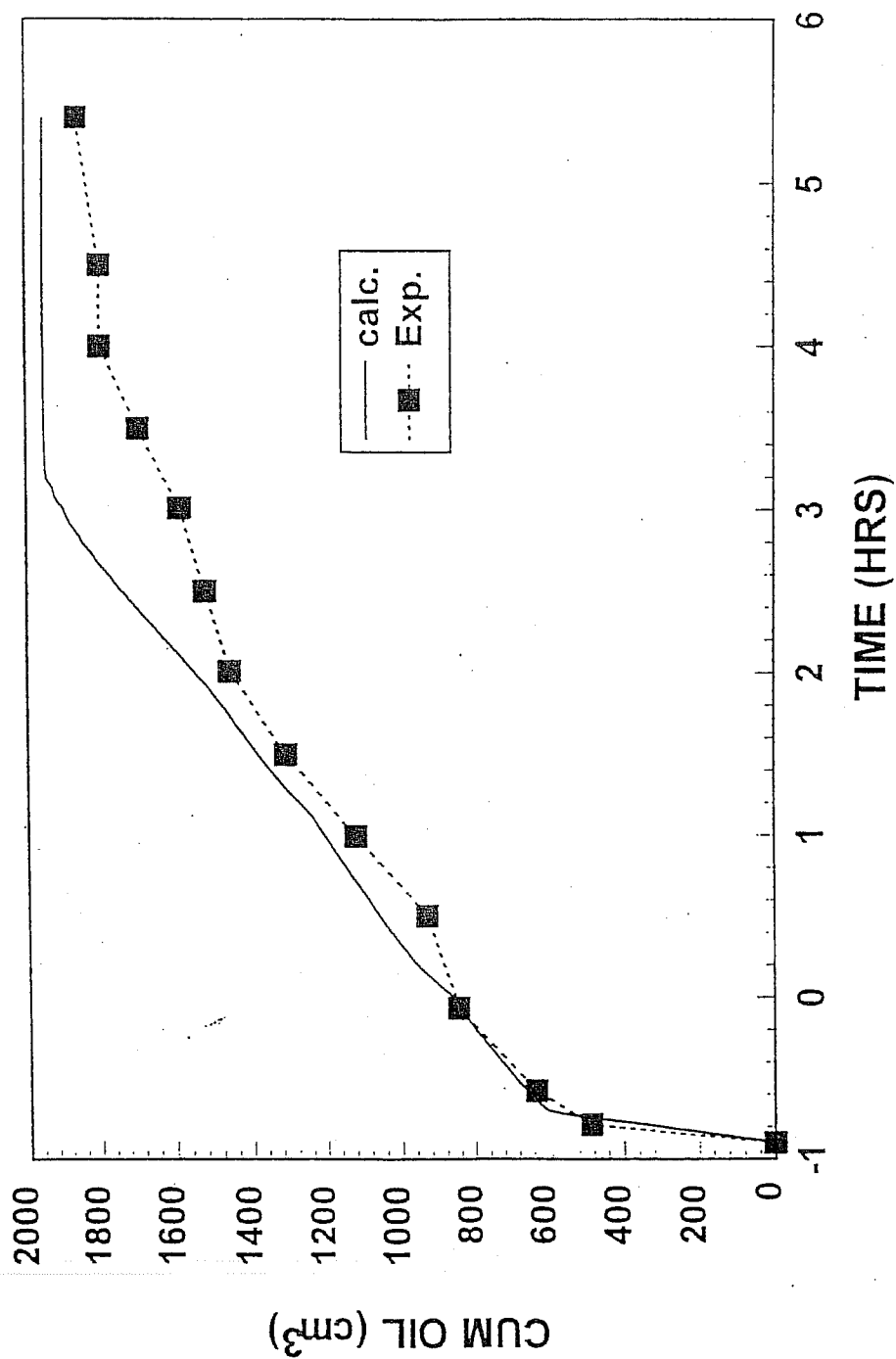
Figure 17: Simulation vs. Exp. Data
air injection test at 3500 psia
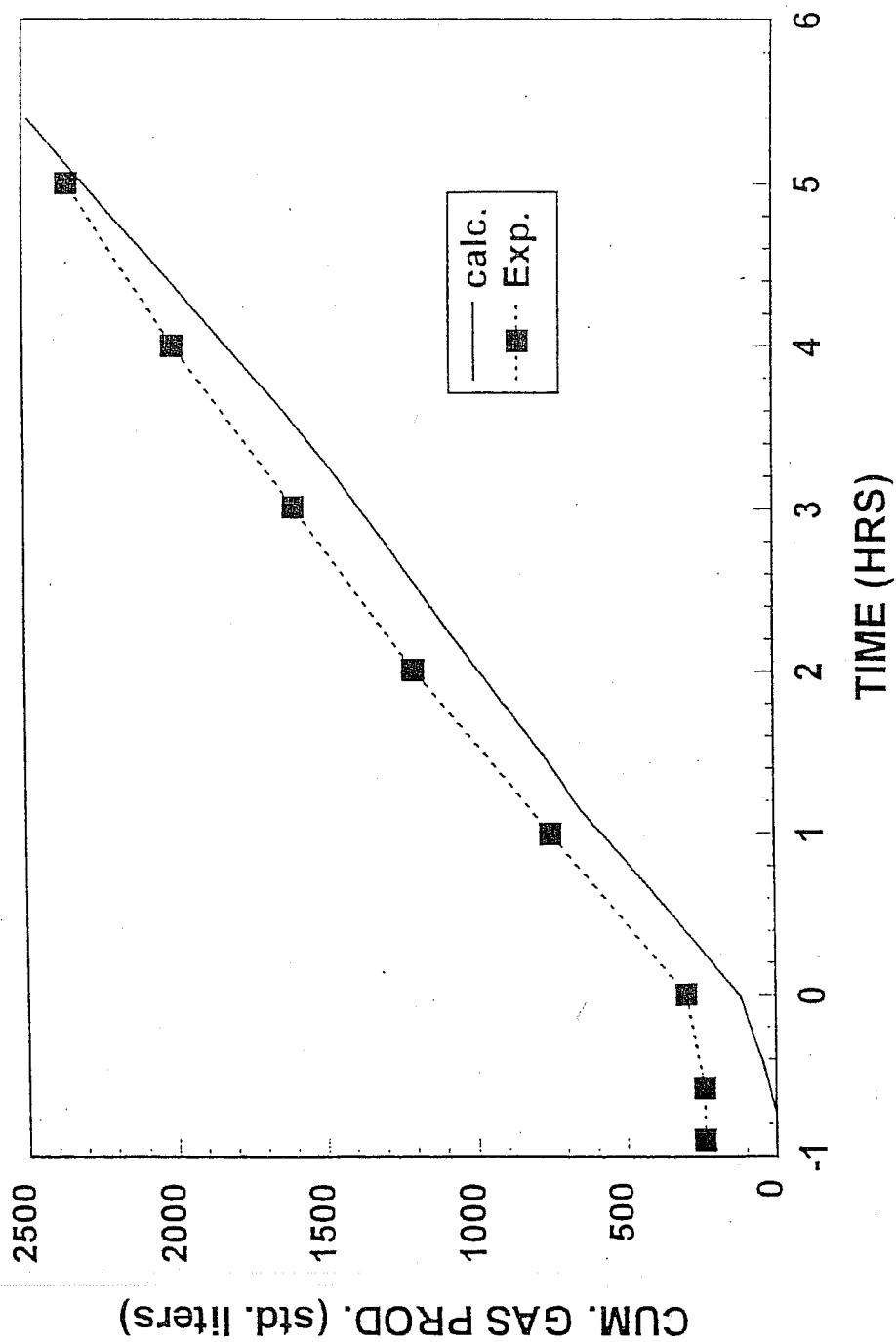
Figure 18: Simulation vs. Exp. Data air injection at 3500 psia
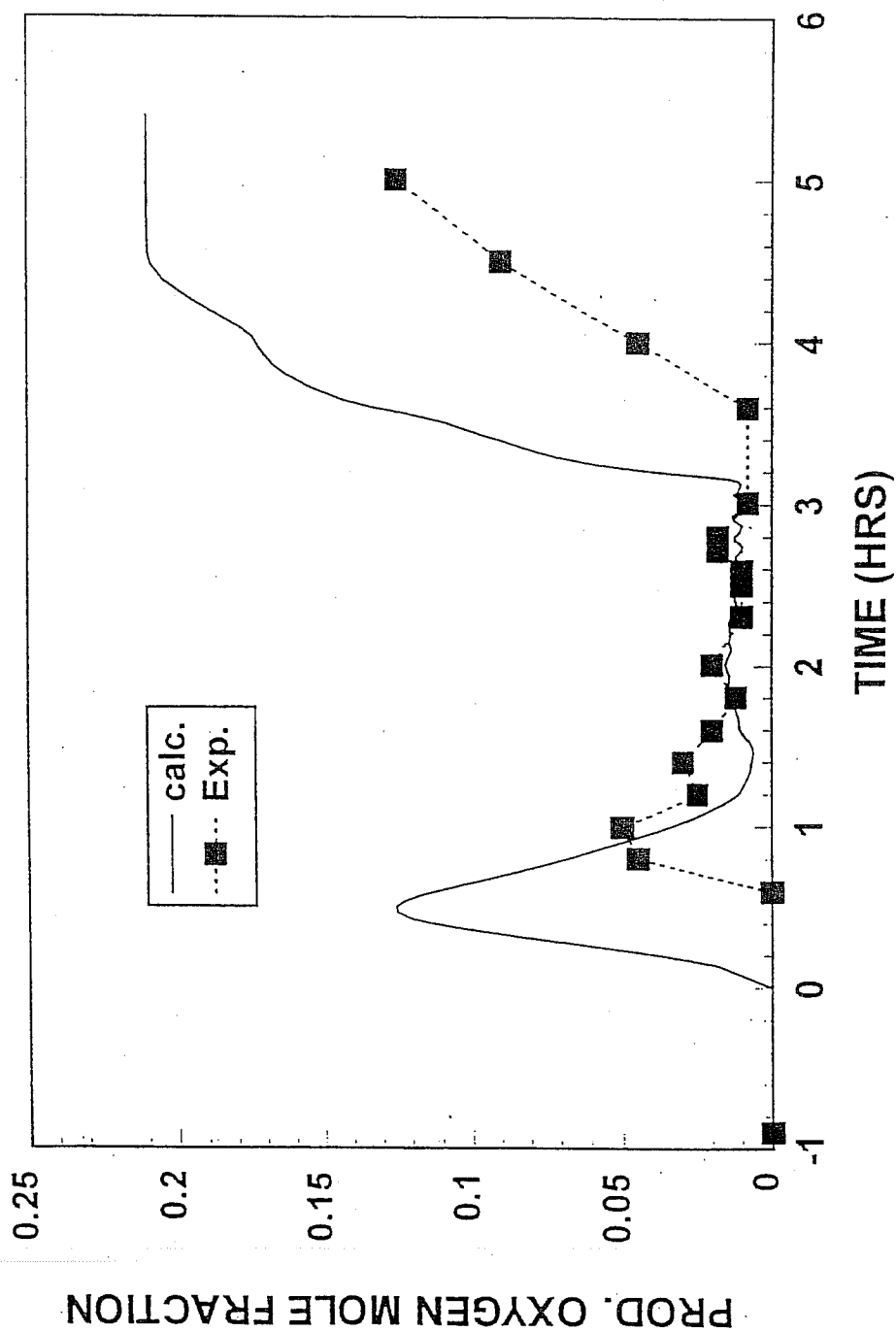
Figure 19: Simulation vs. Exp. Data air injection test at 3500 psia
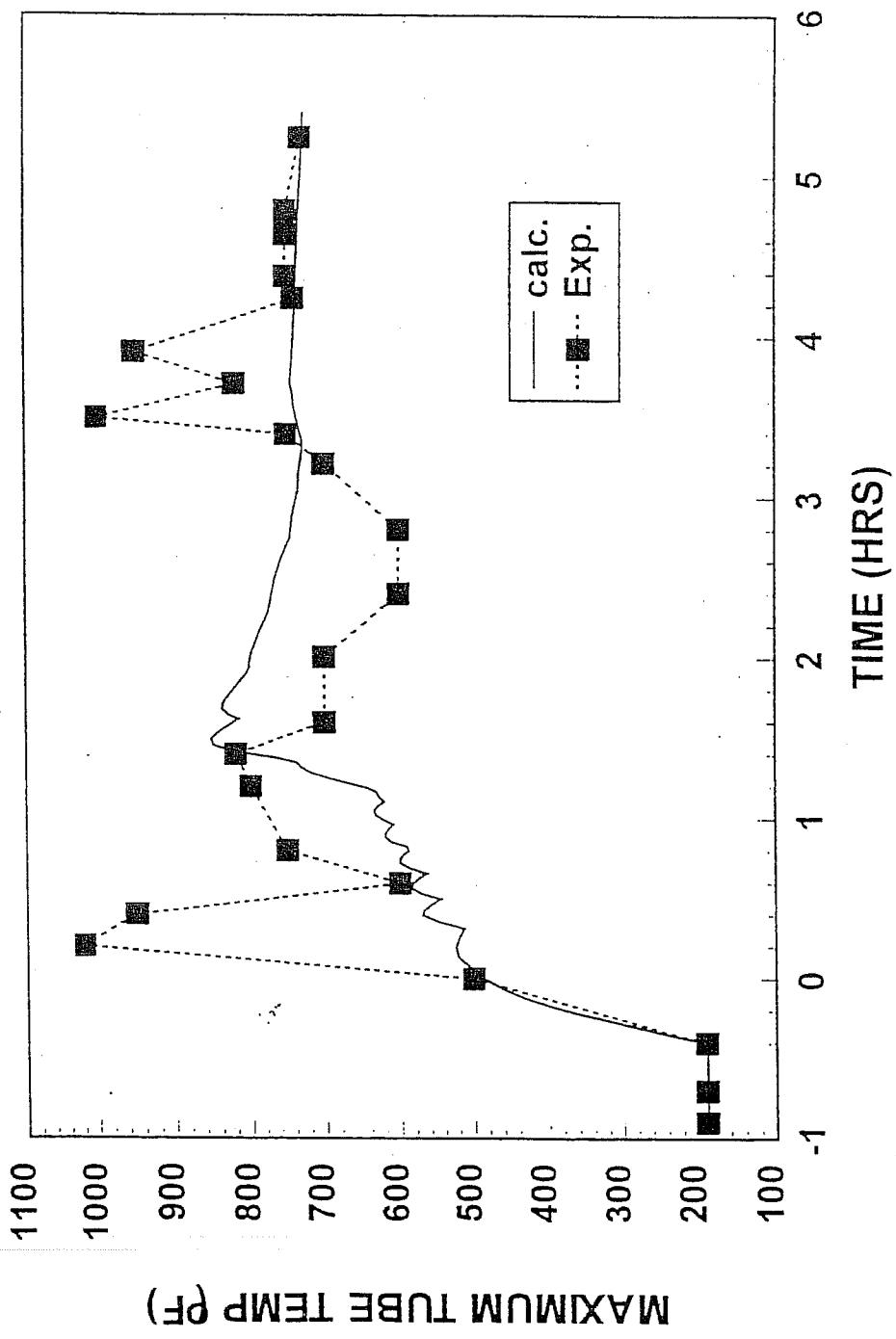
6.0 PRINCIPAL CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn from the work documented in this report:

1. Composition dependent K-Values were developed capable of accounting for the mass transfer associated with flue gas/West Hackberry oil systems.

2. A methodology has been developed for reconciling the ARC and combustion tube data for the purpose of simulating the air injection process.

3. Specifying the liquid saturation to be only oil in the two phase gas-liquid relative permeability data offers an effective means of controlling the quantity of liquid hydrocarbons consumed during the air injection process, through adjustment of the residual oil saturation to gas. The other alternative is to use temperature dependent endpoints which was also attempted and found to intensify convergence problems with STARS.

4. For the purpose of simulating the air injection process with STARS a reaction order of 2.0 with respect to oil concentration significantly improves the computational stability, and the activation energy extracted from the ARC data is probably the only quantity that can be effectively utilized.

5. Strong water-oil capillary pressures will be required to match the water production from the air injection experiments. Several attempts to adjust the relative permeability curves were found not to be effective.

6. The air injection simulations indicate that approximately 40 kcal/gmol of oxygem consumed was used to furnish radial heat losses from the sand pack at 3500 psia compared to the test at 2000 psia.

It is recommended that

1. The K-Value tables developed in this work be expanded to include atmospheric pressure to that surface flashing of the produced hydrocarbon stream will provide a good indication of the oil delivery.

2. Experiments of the bomb calorimetry type be conducted to quantify the enthaly of oxidation of West Hackberry oil. This coupled with the current development of a comprehensive non-adiabatic model capable of accounting for experimentally observed radial energy transfers will close the energy balance of this air injection problem.

REFERENCES

1. Newbold, F.R., Fassihi, R. And Bergman, D.: "Hackberry Fluid Characterization Tests," Amoco Production Company Internal Report F94-P-34, March 30, 1994.

2. Fassihi, M.R.: "Characterization of West Hackberry Oil for Modeling the Air Injection Performance," Amoco Production Company Internal Report. June 7, 1994.

3. Burger, J.G. and Sahuquet, B.C.: "Chemical Aspects of In-Situ Combustion--Heat of Combustion and Kinetics," Soc. Pet. Eng. J. (Oct. 1972) 410-422; Trans. AIME, Vol. 253.

4. Belgrave, J.D.M., Moore, R.G. and Bennion, D.W.: "The Thermal Behavior of Vertically Operated Near-Adiabatic In-Situ Combustion Tubes," J. Pet. Sci. Eng., 5(1), 1990, pp. 51-65.

APPENDICES

APPENDIX A-1

```
**  ============== INPUT/OUTPUT CONTROL  =======================
**  USE DEFAULT FILENAMES:
*filenames *output
          *index-out
          *main-results-out


**  SIMULATION RUN DESCRIPTION:
*title1 'West Hackberry Flue Gas Coreflood: Exp 1'
*title2 'Initial Core Press. = 3500 psig, Core Temp. = 201 F'
*title3 'Run 1: Conditions as provided by the M.R. Fassihi Report'


**  INPUT AND OUTPUT UNITS:
*inunit  field except  1 1  ** hrs instead of days
                except 11 3  ** cm3 instead of bbls for well fluid volumes
*outunit field except  1 1  ** hrs instead of days
                except 11 3  ** cm3 instead of bbls for well fluid volumes


**  OUTPUT ITEMS AND FREQUENCY:
*outprn *grid pres         ** oil phase pressure
              oilsat       ** oil saturation
              y            ** gas phase composition
              x            ** oil phase composition
              viso         ** oil viscosity
              masdeno      ** oil phase mass density
              masdeng      ** gas phase mass density


*outsrf special blkvar molfr z  1  40
                blkvar molfr z  2  40
                blkvar molfr z  3  40
                blkvar molfr z  4  40
                blkvar molfr z  5  40
                blkvar molfr z  6  40
                blkvar molfr z  7  40
                blkvar molfr z  8  40
                blkvar molfr z  9  40

*outprn *well *all
*wprn *grid *time
**checkonly


**  ============== GRID AND CORE DESCRIPTION  =================


**  40 BLOCKS IN THE CARTESIAN X(OR I) DIRECTION:
*grid *cart 40 1 1

**  Core O.D. = 2.00 inches.  Cross-sectional area = 0.021817 ft2.
**  Equivalent square block side length is L = 0.147704 ft  (A=L*L).
**
**  Total core length is 8 ft.  Using 40 gridblocks with half-blocks
**  on either end (for boundary conditions to coincide with core inlet
**  and outlet locations) gives di (or dx) = 0.205128 ft.
*di *con 0.205128
*dj *con 0.147704         **dimensions used in the Fassihi report
*dk *con 0.147704
**
**  GRIDBLOCK VOLUME MODIFICATION (END BLOCKS ONLY):
**      KEY      V      AI      AJ      AK
*vamod    2     0.5    1.0     0.5     0.5
*vatype *all  2 38*1  2


**  ROCK (AND ASSOCIATED) PROPERTIES:
*por   *matrix  *con 0.19470      ** porosity.
*permi *matrix  *con 453          ** permeability, kx, md.
*permj *equalsi                   ** ky = kx.
```

```
*permk *equalsi                          ** kz = kx.
*cpor          0.0      ** rock compressibility, 1/psi.
*rockcp       35.0      ** rock volumetric heat capacity, Btu/ft3-F.
*cpc           4.06     ** coke heat capacity, Btu/lbmole-F.
*thconr        1.0      ** rock thermal cconductivity, Btu/ft-hr-F.
*thconw        1.0      ** water phase thermal conductivity, Btu/ft-hr-F.
*thcono        1.0      ** oil phase thermal conductivity, Btu/ft-hr-F.
*thcong        1.0      ** gas phase thermal conductivity, Btu/ft-hr-F.
*thconmix *simple       ** volume weighting of thermal conductivities.


**   ============== FLUID PROPERTIES  ======================


**   MODEL DESCRIPTION:
*model    9    ** total number of components {ncomp}.
          9    ** total number of components in oil, water,
          **      and gas phases {numy}.
          9    ** total number of components in water or oil phases {numx}.
          1    ** number of aqueous components {numw}.

**   COMPONENT NAMES:
*compname   'WATER' 'N2' 'C1' 'CO2' 'C2-C4'
            'C5-C6' 'C7-C11' 'C12-C17' 'C18+'

** COMPOSITION DEPENDENT K-VALUE TABLES:       <<TO EXPAND AND COMPLETE>>
*gasliqkv                    ** Gas/liquid k-value tables follow.
*kvtablim   2000   4000      ** Pressure range, psia. (i.e 2000,3000,4000)
            60     1000      ** Temperature range, F. (i.e. 60, 216,  373,
                             **                      530, 686, 843, 1000)
*kvkeycomp   'N2'            ** Key component for composition dependence.
             'X'             ** Phase for composition dependence.
             0.00            ** Lower composition limit, mole fraction.
             0.25            ** Upper ccomposition limit, mole fraction.

*kvtable 'N2'
**   P =     2000         3000         4000      ** K-value tables for N2:
**         -------      -------      -------
*keycomp                                         ** Table for XN2 = 0.00
            17.36134     12.06577     9.56544
             6.03940      4.19725     3.32748
             5.08641      3.53495     2.80242
             4.74080      3.29475     2.61200
             4.56266      3.17096     2.51386
             4.45409      3.09550     2.45404
             4.38101      3.04471     2.41377
*keycomp                                         ** Table for XN2 = 0.05
            19.30202     13.23451    10.40193
             6.45636      4.42683     3.47936
             5.40303      3.70461     2.91171
             5.02276      3.44387     2.70678
             4.82716      3.30976     2.60138
             4.70809      3.22812     2.53720
             4.62800      3.17320     2.49404
*keycomp                                         ** Table for XN2 = 0.10
            21.45963     14.51645    11.31156
             6.90212      4.66896     3.63817
             5.73935      3.88241     3.02526
             5.32149      3.59974     2.80500
             5.10700      3.45465     2.69194
             4.97656      3.36642     2.62319
             4.88890      3.30712     2.57698
*keycomp                                         ** Table for XN2 = 0.15
            23.85843     15.92257    12.30074
             7.37865      4.92434     3.80422
             6.09661      4.06874     3.14324
             5.63799      3.76266     2.90679
             5.40305      3.60587     2.78566
```

```
              5.26035      3.51064      2.71209
              5.16452      3.44668      2.66268
*keycomp                                               ** Table for XN2 = 0.20
             26.52537     17.46489     13.37642
              7.88808      5.19368      3.97786
              6.47610      4.26401      3.26582
              5.97331      3.93296      3.01227
              5.71627      3.76372      2.88264
              5.56032      3.66104      2.80400
              5.45567      3.59214      2.75123
*keycomp                                               ** Table for XN2 = 0.25
             29.49042     19.15661     14.54617
              8.43268      5.47776      4.15942
              6.87922      4.46866      3.39318
              6.32858      4.11097      3.12158
              6.04764      3.92847      2.98300
              5.87740      3.81789      2.89903
              5.76324      3.74373      2.84272


*kvtable 'C1'
**    P  =     2000         3000         4000         ** K-value tables for C1:
**            -------      -------      -------
*keycomp                                               ** Table for XN2 = 0.00
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828      2.24198      1.95778
              2.97934      2.25034      1.96508
              2.98540      2.25492      1.96908
              2.98923      2.25781      1.97160
              2.99186      2.25980      1.97334
*keycomp                                               ** Table for XN2 = 0.05
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828      2.24198      1.95778
              2.97934      2.25034      1.96508
              2.98540      2.25492      1.96908
              2.98923      2.25781      1.97160
              2.99186      2.25980      1.97334
*keycomp                                               ** Table for XN2 = 0.10
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828      2.24198      1.95778
              2.97934      2.25034      1.96508
              2.98540      2.25492      1.96908
              2.98923      2.25781      1.97160
              2.99186      2.25980      1.97334
*keycomp                                               ** Table for XN2 = 0.15
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828     ·2.24198      1.95778
              2.97934·     2.25034      1.96508
              2.98540      2.25492      1.96908
              2.98923      2.25781      1.97160
              2.99186      2.25980      1.97334
*keycomp                                               ** Table for XN2 = 0.20
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828      2.24198      1.95778
              2.97934      2.25034      1.96508
              2.98540      2.25492      1.96908
              2.98923      2.25781      1.97160
              2.99186      2.25980      1.97334
*keycomp                                               ** Table for XN2 = 0.25
              2.78885      2.10646      1.83944
              2.94163      2.22186      1.94021
              2.96828      2.24198      1.95778
              2.97934      2.25034      1.96508
              2.98540      2.25492      1.96908
```

```
                  2.98923      2.25781      1.97160
                  2.99186      2.25980      1.97334


*kvtable 'CO2'
**    P  =      2000         3000         4000      ** K-value tables for CO2:
**             -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
                  1.40398      1.11397      1.02235
                  1.54130      1.22292      1.12234
                  1.56525      1.24192      1.13978
                  1.57520      1.24981      1.14703
                  1.58065      1.25414      1.15100
                  1.58409      1.25687      1.15350
                  1.58646      1.25875      1.15523
*keycomp                                           ** Table for XN2 = 0.05
                  1.50213      1.13817      1.02686
                  1.67998      1.27292      1.14843
                  1.71133      1.29667      1.16987
                  1.72438      1.30657      1.17879
                  1.73154      1.31199      1.18368
                  1.73606      1.31542      1.18677
                  1.73918      1.31778      1.18890
*keycomp                                           ** Table for XN2 = 0.10
                  1.60715      1.16290      1.03139
                  1.83113      1.32497      1.17514
                  1.87104      1.35385      1.20075
                  1.88770      1.36590      1.21144
                  1.89684      1.37251      1.21730
                  1.90261      1.37669      1.22101
                  1.90659      1.37957      1.22356
*keycomp                                           ** Table for XN2 = 0.15
                  1.71950      1.18816      1.03594
                  1.99589      1.37914      1.20246
                  2.04566      1.41354      1.23244
                  2.06648      1.42792      1.24499
                  2.07791      1.43582      1.25187
                  2.08514      1.44082      1.25623
                  2.09013      1.44426      1.25923
*keycomp                                           ** Table for XN2 = 0.20
                  1.83970      1.21397      1.04051
                  2.17547      1.43554      1.23042
                  2.23658      1.47586      1.26498
                  2.26219      1.49276      1.27946
                  2.27627      1.50206      1.28743
                  2.28518      1.50793      1.29247
                  2.29133      1.51199      1.29594
*keycomp                                           ** Table for XN2 = 0.25
                  1.96831      1.24035      1.04510
                  2.37121      1.49424      1.25902
                  2.44531      1.54093      1.29837
                  2.47644      1.56055      1.31490
                  2.49357      1.57134      1.32399
                  2.50441      1.57818      1.32975
                  2.51189      1.58289      1.33372


*kvtable 'C2-C4'
**    P  =      2000         3000         4000      ** K-value tables for C2-C4:
**             -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
                  0.16126      0.14097      0.14087
                  0.96869      0.84682      0.84619
                  1.28015      1.11910      1.11827
                  1.43366      1.25329      1.25236
                  1.62444      1.33265      1.33166
                  1.58431      1.38499      1.38396
                  1.62674      1.42208      1.42102
*keycomp                                           ** Table for XN2 = 0.05
                  0.04170      0.03300      0.03296
```

```
                 0.94612      0.74864      0.74767
                 1.53731      1.21643      1.21486
                 1.87241      1.48158      1.47967
                 2.32741      1.64874      1.64662
                 2.22823      1.76313      1.76085
                 2.33315      1.84615      1.84377
*keycomp                                              ** Table for XN2 = 0.10
                 0.01078      0.00772      0.00771
                 0.92407      0.66184      0.66062
                 1.84613      1.32223      1.31979
                 2.44543      1.75145      1.74823
                 3.33460      2.03981      2.03606
                 3.13385      2.24451      2.24038
                 3.34631      2.39668      2.39227
*keycomp                                              ** Table for XN2 = 0.15
                 0.00279      0.00181      0.00180
                 0.90254      0.58510      0.58370
                 2.21699      1.43723      1.43380
                 3.19381      2.07048      2.06554
                 4.77763      2.52364      2.51761
                 4.40754      2.85733      2.85050
                 4.79944      3.11139      3.10395
*keycomp                                              ** Table for XN2 = 0.20
                 0.00072      0.00042      0.00042
                 0.88151      0.51726      0.51574
                 2.66234      1.56223      1.55764
                 4.17122      2.44763      2.44044
                 6.84514      3.12223      3.11306
                 6.19891      3.63745      3.62677
                 6.88360      4.03922      4.02736
*keycomp                                              ** Table for XN2 = 0.25
                 0.00019      0.00010      0.00010
                 0.86097      0.45729      0.45569
                 3.19715      1.69811      1.69219
                 5.44776      2.89347      2.88338
                 9.80736      3.86280      3.84933
                 8.71834      4.63058      4.61444
                 9.87279      5.24374      5.22546


*kvtable 'C5-C6'
**   P =    2000         3000         4000          ** K-value tables for C5-C6:
**          -------      -------      -------
*keycomp                                              ** Table for XN2 = 0.00
                 0.00167      0.00174      0.00197
                 0.20350      0.21248      0.24001
                 0.40127      0.41896      0.47324
                 0.52621      0.54941      0.62059
                 0.60883      0.63568      0.71804
                 0.66691      0.69631      0.78653
                 0.70979      0.74109      0.83710
*keycomp                                              ** Table for XN2 = 0.05
                 4.78E-04     5.03E-04     5.82E-04
                 0.14909      0.15698      0.18159
                 0.33569      0.35346      0.40887
                 0.46416      0.48873      0.56535
                 0.55256      0.58181      0.67303
                 0.61614      0.64876      0.75047
                 0.66380      0.69894      0.80851
*keycomp                                              ** Table for XN2 = 0.10
                 1.37E-04     1.45E-04     1.72E-04
                 0.10923      0.11598      0.13740
                 0.28082      0.29819      0.35325
                 0.40942      0.43474      0.51502
                 0.50149      0.53251      0.63084
                 0.56924      0.60445      0.71606
                 0.62079      0.65918      0.78090
*keycomp                                              ** Table for XN2 = 0.15
                 3.92E-05     4.20E-05     5.10E-05
```

```
         0.08002      0.08569      0.10396
         0.23493      0.25157      0.30520
         0.36114      0.38673      0.46917
         0.45515      0.48739      0.59130
         0.52592      0.56317      0.68324
         0.58056      0.62169      0.75423
*keycomp                                        ** Table for XN2 = 0.20
         1.12E-05     1.21E-05     1.51E-05
         0.05862      0.06331      0.07866
         0.19653      0.21224      0.26369
         0.31855      0.34401      0.42741
         0.41308      0.44609      0.55423
         0.48588      0.52471      0.65191
         0.54294      0.58633      0.72847
*keycomp                                        ** Table for XN2 = 0.25
         3.22E-06     3.51E-06     4.46E-06
         0.04295      0.04677      0.05951
         0.16441      0.17905      0.22782
         0.28099      0.30601      0.38936
         0.37490      0.40829      0.51949
         0.44890      0.48888      0.62203
         0.50776      0.55298      0.70359


*kvtable 'C7-C11'
**    P  =     2000         3000         4000      ** K-value tables for C7-C11:
**            -------      -------      -------
*keycomp                                        ** Table for XN2 = 0.00
         1.05E-11     1.26E-11     1.53E-11
         0.03791      0.04543      0.05524
         0.11775      0.14113      0.17160
         0.17641      0.21143      0.25709
         0.21709      0.26018      0.31636
         0.24630      0.29519      0.35893
         0.26812      0.32134      0.39073
*keycomp                                        ** Table for XN2 = 0.05
         2.21E-13     2.72E-13     3.41E-13
         0.02299      0.02833      0.03549
         0.08493      0.10465      0.13110
         0.13535      0.16676      0.20892
         0.17191      0.21182      0.26536
         0.19884      0.24500      0.30693
         0.21929      0.27019      0.33849
*keycomp                                        ** Table for XN2 = 0.10
         4.65E-15     5.89E-15     7.60E-15
         0.01395      0.01767      0.02281
         0.06126      0.07760      0.10016
         0.10384      0.13153      0.16978
         0.13614      0.17245      0.22259
         0.16053      0.20334      0.26247
         0.17935      0.22718      0.29323
*keycomp                                        ** Table for XN2 = 0.15
         9.78E-17     1.27E-16     1.69E-16
         0.00846      0.01102      0.01465
         0.04419      0.05754      0.07652
         0.07967      0.10374      0.13797
         0.10781      0.14039      0.18671
         0.12960      0.16877      0.22444
         0.14669      0.19101      0.25403
*keycomp                                        ** Table for XN2 = 0.20
         2.06E-18     2.75E-18     3.77E-18
         0.00513      0.00687      0.00942
         0.03187      0.04267      0.05846
         0.06112      0.08183      0.11212
         0.08538      0.11430      0.15661
         0.10463      0.14007      0.19193
         0.11997      0.16060      0.22006
*keycomp                                        ** Table for XN2 = 0.25
         4.33E-20     5.96E-20     8.41E-20
```

```
                0.00311      0.00429      0.00605
                0.02299      0.03164      0.04466
                0.04690      0.06454      0.09111
                0.06761      0.09305      0.13137
                0.08447      0.11626      0.16413
                0.09812      0.13504      0.19064

*kvtable 'C12-C17'
**   P  =      2000         3000         4000       ** K-value tables for C12-C17:
**             -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
                8.52E-12     1.28E-11     1.70E-11
                0.001325     0.001987     0.002649
                0.008499     0.012749     0.016998
                0.017180     0.025769     0.034359
                0.024874     0.037312     0.049749
                0.031253     0.046880     0.06250603
                0.036488     0.054732     0.07297534
*keycomp                                           ** Table for XN2 = 0.05
                3.34E-13     5.27E-13     7.29E-13
                5.71E-04     9.01E-04     1.25E-03
                4.64E-03     7.32E-03     1.01E-02
                0.01025      0.01619      0.02239
                0.01555      0.02457      0.03397
                0.02012      0.03177      0.04394
                0.02396      0.03783      0.05232
*keycomp                                           ** Table for XN2 = 0.10
                1.31E-14     2.18E-14     3.12E-14
                2.46E-04     4.09E-04     5.86E-04
                2.53E-03     4.21E-03     6.03E-03
                6.11E-03     1.02E-02     1.46E-02
                9.73E-03     1.62E-02     2.32E-02
                0.01295      0.02154      0.03089
                0.01573      0.02615      0.03752
*keycomp                                           ** Table for XN2 = 0.15
                5.13E-16     8.98E-16     1.34E-15
                1.06E-04     1.85E-04     2.76E-04
                1.38E-03     2.42E-03     3.59E-03
                3.65E-03     6.39E-03     9.50E-03
                6.08E-03     1.06E-02     1.58E-02
                8.34E-03     1.46E-02     2.17E-02
                1.03E-02     1.81E-02     2.69E-02
*keycomp                                           ** Table for XN2 = 0.20
                2.01E-17     3.70E-17     5.72E-17
                4.56E-05     8.41E-05     1.30E-04
                7.53E-04     1.39E-03     2.14E-03
                2.18E-03     4.01E-03     6.19E-03
                3.80E-03     7.01E-03     1.08E-02
                5.37E-03     9.89E-03     1.53E-02
                6.78E-03     1.25E-02     1.93E-02
*keycomp                                           ** Table for XN2 = 0.25
                7.87E-19     1.53E-18     2.45E-18
                1.96E-05     3.81E-05     6.10E-05
                4.11E-04     7.97E-04     1.28E-03
                1.30E-03     2.52E-03     4.03E-03
                2.38E-03     4.62E-03     7.39E-03
                3.45E-03     6.71E-03     1.07E-02
                4.45E-03     8.64E-03     1.38E-02

*kvtable 'C18+'
**   P  =      2000         3000         4000       ** K-value tables for C18+:
**             -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
                3.94E-17     1.33E-16     2.13E-16
                1.32E-05     4.49E-05     7.15E-05
                1.98E-04     6.72E-04     1.07E-03
                5.54E-04     1.88E-03     2.99E-03
                9.54E-04     3.23E-03     5.15E-03
```

```
          1.33E-03   4.52E-03   7.20E-03
          1.67E-03   5.67E-03   9.03E-03
*keycomp                                    ** Table for XN2 = 0.05
          6.33E-19   2.45E-18   4.11E-18
          3.88E-06   1.50E-05   2.52E-05
          7.80E-05   3.02E-04   5.06E-04
          2.44E-04   9.46E-04   1.59E-03
          4.46E-04   1.73E-03   2.89E-03
          6.46E-04   2.50E-03   4.20E-03
          8.31E-04   3.22E-03   5.40E-03
*keycomp                                    ** Table for XN2 = 0.10
          1.02E-20   4.50E-20   7.94E-20
          1.13E-06   5.02E-06   8.86E-06
          3.07E-05   1.36E-04   2.40E-04
          1.08E-04   4.76E-04   8.40E-04
          2.08E-04   9.22E-04   1.63E-03
          3.13E-04   1.39E-03   2.45E-03
          4.13E-04   1.83E-03   3.23E-03
*keycomp                                    ** Table for XN2 = 0.15
          1.63E-22   8.26E-22   1.53E-21
          3.32E-07   1.68E-06   3.12E-06
          1.21E-05   6.11E-05   1.13E-04
          4.74E-05   2.40E-04   4.45E-04
          9.74E-05   4.92E-04   9.14E-04
          1.52E-04   7.68E-04   1.43E-03
          2.05E-04   1.04E-03   1.93E-03
*keycomp                                    ** Table for XN2 = 0.20
          2.63E-24   1.52E-23   2.96E-23
          9.73E-08   5.62E-07   1.10E-06
          4.76E-06   2.75E-05   5.37E-05
          2.09E-05   1.21E-04   2.36E-04
          4.55E-05   2.63E-04   5.14E-04
          7.36E-05   4.25E-04   8.31E-04
          1.02E-04   5.90E-04   1.15E-03
*keycomp                                    ** Table for XN2 = 0.25
          4.22E-26   2.79E-25   5.73E-25
          2.85E-08   1.88E-07   3.87E-07
          1.87E-06   1.24E-05   2.54E-05
          9.19E-06   6.07E-05   1.25E-04
          2.13E-05   1.40E-04   2.89E-04
          3.57E-05   2.36E-04   4.85E-04
          5.07E-05   3.35E-04   6.89E-04


**   MOLECULAR WEIGHTS:
*cmm          0           ** WATER      use internal default value
            28.10         ** N2
            16.04         ** C1
            44.01         ** CO2
            39.62         ** C2-C4
            79.99         ** C5-C6
           118.51         ** C7-C11
           190.56         ** C12-C17
           358.96         ** C18+


**   CRITICAL PRESSURE (PSIA):
*pcrit        0           ** WATER      use internal default value
           493.1          ** N2
           666.4          ** C1
          1070.7          ** CO2
           649.3          ** C2-C4
           460.3          ** C5-C6
           440.2          ** C7-C11
           287.9          ** C12-C17
           156.1          ** C18+


**   CRITICAL TEMPERATURE (deg F):
*tcrit        0           ** WATER      use internal default value
          -232.47         ** N2
```

C–60

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                 -116.67        **  C1
                   87.93        **  CO2
                  163.13        **  C2-C4
                  415.53        **  C5-C6
                  620.73        **  C7-C11
                  939.73        **  C12-C17
                 1173.33        **  C18+


**   REFERENCE CONDITIONS:
*prsr 14.7  *temr 60.0  *psurf 15.0  *tsurf 70.0


**   ENTHALPIES: MODEL DEFAULTS FOR FLUID EMPLOYED.
**   i.e  0.5  Btu/lb-F for components in the oil phase
**   and  0.25 Btu/lb-F for components in the gas phase.


**   LIQUID PHASE MASS DENSITIES AT REFERENCE CONDITIONS (LB/FT3):
*massden       0           ** WATER        ** use internal default value
              50.56        ** N2           ** apparent density from Katz
              18.72        ** C1           ** 18.72 (katz), 26.52 (prausnitz)
              51.19        ** CO2          ** apparent density from Katz
              27.87        ** C2-C4
              40.46        ** C5-C6
              49.46        ** C7-C11
              53.46        ** C12-C17
              56.02        ** C18+


**   LIQUID PHASE ISOTHERMAL COMPRESSIBILITIES (1/PSI):
*cp            0           ** WATER    use internal default value
             5.1e-05       ** N2
             6.0e-05       ** C1
             8.4e-05       ** CO2            ** pratz monograph pg. 209.
             5.4e-05       ** C2-C4
             1.2e-05       ** C5-C6
             5.7e-06       ** C7-C11
             4.4e-06       ** C12-C17
             3.8e-06       ** C18+


**   LIQUID PHASE THERMAL EXPANSION COEFFICIENT (FIRST COEF., 1/F):
*ct1          0.0e+00       ** WATER
             5.1e-04        ** N2
             5.1e-04        ** C1        ** <<ALL TO BE EVALUATED
             5.1e-04        ** CO2       **    FOR IN SITU COMBUSTION
             5..1e-04       ** C2-C4     **    RUNS>>
             5.1e-04        ** C5-C6
             5.1e-04        ** C7-C11
             5.1e-04        ** C12-C17
             5.1e-04        ** C18+


**   GAS PHASE VISCOSITIES:
*gviscor                          ** enable high gas density correction
**   (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avg         0            ** WATER    use internal default value
           1.6746E-16     ** N2
           7.4588E-09     ** C1
           2.0806E-15     ** CO2
           2.0806E-15     ** C2-C4
           1.7370E-15     ** C5-C6
           1.7370E-15     ** C7-C11
           1.7370E-15     ** C12-C17
           1.3250E-23     ** C18+


*bvg         0            ** WATER   use internal default value
           5.2260         ** N2
           2.2786         ** C1
           4.5559         ** CO2
           4.5559         ** C2-C4
           4.5832         ** C5-C6
```

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                    4.5832      ** C7-C11
                    4.5832      ** C12-C17
                    7.4030      ** C18+

**   LIQUID VISCOSITIES:
**   (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avisc      0              ** WATER    use internal default value
            0.0106140      ** N2
            0.0109660      ** C1
            0.0083353      ** CO2
            0.0084364      ** C2-C4
            0.0085699      ** C5-C6
            0.0172210      ** C7-C11
            0.0274550      ** C12-C17
            0.0989540      ** C18+

*bvisc          0          ** WATER    use internal default value
            2010.2         ** N2
            1982.1         ** C1
            1167.1         ** CO2
            1254.5         ** C2-C4
            2021.6         ** C5-C6
            2415.0         ** C7-C11
            2661.1         ** C12-C17
            3412.4         ** C18+


**   NO CHEMICAL REACTIONS SPECIFIED IN THIS DATA SET.
**surflash *kvalue

**   ============== ROCK-FLUID PROPERTIES  =====================
*rockfluid


*rpt 1      ** Rock type number of the following data.
**stone1       ** Stone's model I for three-phase rel perms (FASSIHI'S WORK).
**watwet       ** Specifying a water-wet system.

**   OIL-WATER RELATIVE PERMEABILITY:
*swt
**     Sw         Krw          Krow
**   -------    --------     --------
     0.0000     0.0000       1.0000
     1.0000     1.0000       0.0000

** GAS-LIQUID RELATIVE PERMEABILITY:
*slt
**     Sl         Krg          Krog                  ** From R. FASSIHI'S
**   -------    --------     --------                ** matching of fluegas
     0.2500     1.0000       0.00000                 ** coreflood experiments.
     0.3000     0.8600       0.00010
     0.3500     0.7940       0.00034
     0.4000     0.7350       0.00125
     0.4500     0.6300       0.00430
     0.5000     0.5000       0.01170
     0.5500     0.4300       0.03410
     0.6000     0.3410       0.07940
     0.6500     0.2510       0.15800
     0.7000     0.2000       0.27100
     0.7500     0.1470       0.42900
     0.8000     0.0930       0.63100
     0.8500     0.0400       0.79400
     0.9000     0.0100       0.92600
     0.9500     0.0010       0.96200
     0.9750     0.0001       0.98100
     1.0000     0.0000       1.00000

*krtype *con 1   ** Above rock data assigned to all gridblocks.
```

```
**   ============== INITIAL CONDITIONS  =======================
*initial


*pres *con 3500.0        ** Initial core pressure, psia.
*sw   *con    0.00001    ** Initial core water saturation.
*so   *con    0.99999    ** Initial core oil saturation.
*sg   *con    0.00000    ** Initial core gas saturation.
*temp *con  201.0        ** Initial core temperature, deg F.


** INITIAL OIL PHASE MOLE FRACTIONS:
*molefrac *oil *con
              0.000000      ** WATER
              0.010300      ** N2
              0.427600      ** C1
              0.004800      ** CO2
              0.053900      ** C2-C4
              0.019500      ** C5-C6
              0.159188      ** C7-C11
              0.148904      ** C12-C17
              0.175808      ** C18+


**   ============== NUMERICAL CONTROL  =======================
*numerical


**   ALL OF THESE CAN BE DEFAULTED.
*north 8  *newtoncyc 8  *itermax 15
*norm      press 15   satur .1    temp 40  y .1    x .1
*converge press .15  satur .002  temp .5  y .002  x .002


**   MAXIMUM NUMBER OF TIMESTEPS:
*maxsteps 1000                  **  DEFAULT = 9999


*run
**   ============== RECURRENT DATA  =======================

*time            0.0              ** Starting time for this section, hrs.
   *dtwell       0.00024          ** Starting time step size, hrs.
   *dtmax        0.5              ** Maximum time step size, 0.024 hrs.

   *well 1 'INJECTOR'
   *injector 1                    ** Well #1 is an injector.
   *operate *gas 1137.0           ** Gas injection rate, scm3/hr
                                  ** at core conditions = 6.45 cm3/hr.

   *incomp  *gas
              0.00     ** WATER
              0.85     ** N2         Composition of
              0.00     ** C1         injected gas.
              0.15     ** CO2
              0.00     ** C2-C4
              0.00     ** C5-C6
              0.00     ** C7-C11
              0.00     ** C12-C17
              0.00     ** C18+
   *tinjov   201.00        ** Temperature of the injected gas, deg F.
   *geometry *i -1 1 1 0   ** Linear pressure drop at beginning of tube.
   *perf *geo 1  ** i  j  k   Well #1 completed in block (1,1,1)
                 1  1  1



   *well 2 'PRODUCER'
   *producer 2                ** Well #2 is a producer.
   *operate *bhp 3500.0    ** Back pressure at producer is 3500 psia.
   *geometry *i -1 1 1 0   ** Linear pressure drop at tube end.
   *perf *geo 2  ** i   j   k   Well #2 completed in block (40,1,1).
                 40   1   1
*time          4.8              ** At 4 hrs change max step size to 0.24 hrs.
```

```
      *dtmax    1.0
*time          10.0
*time          24.0
*time          48.0        ** Pause for detailed printouts.
*time          72.0
*time          96.0
*time         120.0
*time         144.0
*time         168.0
      *stop
```

```
**   ============== INPUT/OUTPUT CONTROL  =======================
**   USE DEFAULT FILENAMES:
*filenames *output
           *index-out
           *main-results-out

**  SIMULATION RUN DESCRIPTION:
*title1 'West Hackberry Flue Gas Coreflood: Exp 2'
*title2 'Initial Core Press. = 2200 psig, Core Temp. = 190 F'
*title3 'Run 1: Conditions as provided by the M.R. Fassihi Report'

**   INPUT AND OUTPUT UNITS:
*inunit  field except  1 1  ** hrs instead of days
              except 11 3  ** cm3 instead of bbls for well fluid volumes
*outunit field except  1 1  ** hrs instead of days
              except 11 3  ** cm3 instead of bbls for well fluid volumes

**   OUTPUT ITEMS AND FREQUENCY:
*outprn *grid pres          ** oil phase pressure
             oilsat         ** oil saturation
             y              ** gas phase composition
             x              ** oil phase composition
             viso           ** oil viscosity
             masdeno        ** oil phase mass density
             masdeng        ** gas phase mass density

*outsrf special blkvar molfr z  1  40
                blkvar molfr z  2  40
                blkvar molfr z  3  40
                blkvar molfr z  4  40
                blkvar molfr z  5  40
                blkvar molfr z  6  40
                blkvar molfr z  7  40
                blkvar molfr z  8  40
                blkvar molfr z  9  40

*outprn *well *all
*wprn *grid *time
**checkonly

**   ============== GRID AND CORE DESCRIPTION ==================


**   40 BLOCKS IN THE CARTESIAN X(OR I) DIRECTION:
*grid *cart 40 1 1

**   Core O.D. = 2.00 inches.  Cross-sectional area = 0.021817 ft2.
**   Equivalent square block side length is L = 0.147704 ft  (A=L*L).
**
**   Total core length is 8 ft.  Using 40 gridblocks with half-blocks
**   on either end (for boundary conditions to coincide with core inlet
**   and outlet locations) gives di (or dx) = 0.205128 ft.
*di *con 0.205128
*dj *con 0.147704          **dimensions used in the Fassihi report
*dk *con 0.147704
**
**   GRIDBLOCK VOLUME MODIFICATION (END BLOCKS ONLY):
**       KEY      V      AI      AJ      AK
*vamod    2     0.5     1.0     0.5     0.5
*vatype *all  2  38*1  2

**   ROCK (AND ASSOCIATED) PROPERTIES:
*por   *matrix   *con 0.19470      ** porosity.
*permi *matrix   *con 453          ** permeability, kx, md.
*permj *equalsi                    ** ky = kx.
```

```
*permk *equalsi                        ** kz = kx.
*cpor       0.0      ** rock compressibility, 1/psi.
*rockcp     35.0     ** rock volumetric heat capacity, Btu/ft3-F.
*cpc        4.06     ** coke heat capacity, Btu/lbmole-F.
*thconr     1.0      ** rock thermal cconductivity, Btu/ft-hr-F.
*thconw     1.0      ** water phase thermal conductivity, Btu/ft-hr-F.
*thcono     1.0      ** oil phase thermal conductivity, Btu/ft-hr-F.
*thcong     1.0      ** gas phase thermal conductivity, Btu/ft-hr-F.
*thconmix *simple    ** volume weighting of thermal conductivities.


**  ============== FLUID PROPERTIES  =====================


**  MODEL DESCRIPTION:
*model    9   ** total number of components {ncomp}.
          9   ** total number of components in oil, water,
              **   and gas phases {numy}.
          9   ** total number of components in water or oil phases {numx}.
          1   ** number of aqueous components {numw}.

**  COMPONENT NAMES:
*compname  'WATER' 'N2' 'C1' 'CO2' 'C2-C4'
           'C5-C6' 'C7-C11' 'C12-C17' 'C18+'

**  COMPOSITION DEPENDENT K-VALUE TABLES:        <<TO EXPAND AND COMPLETE>>
*gasliqkv                    ** Gas/liquid k-value tables follow.
*kvtablim   2000   4000      ** Pressure range, psia. (i.e 2000,3000,4000)
            60     1000      ** Temperature range, F. (i.e. 60, 216,  373,
                             **                         530, 686, 843, 1000)
*kvkeycomp   'N2'            ** Key component for composition dependence.
             'X'            ** Phase for composition dependence.
             0.00           ** Lower composition limit, mole fraction.
             0.25           ** Upper ccomposition limit, mole fraction.

*kvtable 'N2'
**   P =     2000       3000       4000     ** K-value tables for N2:
**         -------    -------    -------
*keycomp
            17.36134   12.06577    9.56544  ** Table for XN2 = 0.00
             6.03940    4.19725    3.32748
             5.08641    3.53495    2.80242
             4.74080    3.29475    2.61200
             4.56266    3.17096    2.51386
             4.45409    3.09550    2.45404
             4.38101    3.04471    2.41377
*keycomp
            19.30202   13.23451   10.40193  ** Table for XN2 = 0.05
             6.45636    4.42683    3.47936
             5.40303    3.70461    2.91171
             5.02276    3.44387    2.70678
             4.82716    3.30976    2.60138
             4.70809    3.22812    2.53720
             4.62800    3.17320    2.49404
*keycomp
            21.45963   14.51645   11.31156  ** Table for XN2 = 0.10
             6.90212    4.66896    3.63817
             5.73935    3.88241    3.02526
             5.32149    3.59974    2.80500
             5.10700    3.45465    2.69194
             4.97656    3.36642    2.62319
             4.88890    3.30712    2.57698
*keycomp
            23.85843   15.92257   12.30074  ** Table for XN2 = 0.15
             7.37865    4.92434    3.80422
             6.09661    4.06874    3.14324
             5.63799    3.76266    2.90679
             5.40305    3.60587    2.78566
```

```
                5.26035         3.51064         2.71209
                5.16452         3.44668         2.66268
*keycomp                                                    ** Table for XN2 = 0.20
               26.52537        17.46489        13.37642
                7.88808         5.19368         3.97786
                6.47610         4.26401         3.26582
                5.97331         3.93296         3.01227
                5.71627         3.76372         2.88264
                5.56032         3.66104         2.80400
                5.45567         3.59214         2.75123
*keycomp                                                    ** Table for XN2 = 0.25
               29.49042        19.15661        14.54617
                8.43268         5.47776         4.15942
                6.87922         4.46866         3.39318
                6.32858         4.11097         3.12158
                6.04764         3.92847         2.98300
                5.87740         3.81789         2.89903
                5.76324         3.74373         2.84272


*kvtable 'C1'
**    P =      2000            3000            4000        ** K-value tables for C1:
**            -------         -------         -------
*keycomp                                                    ** Table for XN2 = 0.00
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
                2.98923         2.25781         1.97160
                2.99186         2.25980         1.97334
*keycomp                                                    ** Table for XN2 = 0.05
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
                2.98923         2.25781         1.97160
                2.99186         2.25980         1.97334
*keycomp                                                    ** Table for XN2 = 0.10
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
                2.98923         2.25781         1.97160
                2.99186         2.25980         1.97334
*keycomp                                                    ** Table for XN2 = 0.15
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
                2.98923         2.25781         1.97160
                2.99186         2.25980         1.97334
*keycomp                                                    ** Table for XN2 = 0.20
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
                2.98923         2.25781         1.97160
                2.99186         2.25980         1.97334
*keycomp                                                    ** Table for XN2 = 0.25
                2.78885         2.10646         1.83944
                2.94163         2.22186         1.94021
                2.96828         2.24198         1.95778
                2.97934         2.25034         1.96508
                2.98540         2.25492         1.96908
```

```
            2.98923      2.25781     ·1.97160
            2.99186      2.25980      1.97334

*kvtable 'CO2'
**    P  =     2000         3000         4000      ** K-value tables for CO2:
**          -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
            1.40398    · 1.11397      1.02235
            1.54130      1.22292      1.12234
            1.56525      1.24192      1.13978
            1.57520      1.24981      1.14703
            1.58065      1.25414      1.15100
            1.58409      1.25687      1.15350
            1.58646      1.25875      1.15523
*keycomp                                           ** Table for XN2 = 0.05
            1.50213      1.13817      1.02686
            1.67998      1.27292      1.14843
            1.71133      1.29667      1.16987
            1.72438      1.30657      1.17879
            1.73154      1.31199      1.18368
            1.73606      1.31542      1.18677
            1.73918      1.31778      1.18890
*keycomp                                           ** Table for XN2 = 0.10
            1.60715      1.16290      1.03139
            1.83113      1.32497      1.17514
            1.87104      1.35385      1.20075
            1.88770      1.36590      1.21144
            1.89684      1.37251      1.21730
            1.90261      1.37669      1.22101
            1.90659      1.37957      1.22356
*keycomp                                           ** Table for XN2 = 0.15
            1.71950      1.18816      1.03594
            1.99589      1.37914      1.20246
            2.04566      1.41354      1.23244
            2.06648      1.42792      1.24499
            2.07791      1.43582      1.25187
            2.08514      1.44082      1.25623
            2.09013      1.44426      1.25923
*keycomp                                           ** Table for XN2 = 0.20
            1.83970      1.21397     ·1.04051
            2.17547      1.43554      1.23042
            2.23658      1.47586      1.26498
            2.26219      1.49276      1.27946
            2.27627      1.50206      1.28743
            2.28518      1.50793      1.29247
            2.29133      1.51199      1.29594
*keycomp                                           ** Table for XN2 = 0.25
            1.96831      1.24035     ·1.04510
            2.37121      1.49424      1.25902
            2.44531      1.54093      1.29837
            2.47644      1.56055      1.31490
            2.49357      1.57134      1.32399
           ·2.50441      1.57818      1.32975
            2.51189      1.58289      1.33372

*kvtable 'C2-C4'
**    P  =     2000         3000         4000   .  ** K-value tables for C2-C4:
**          -------      -------      -------
*keycomp                                           ** Table for XN2 = 0.00
            0.16126      0.14097  ·   0.14087
            0.96869      0.84682      0.84619
            1.28015      1.11910      1.11827
          ' 1.43366      1.25329      1.25236
            1.62444      1.33265      1.33166
            1.58431      1.38499      1.38396
            1.62674      1.42208      1.42102
*keycomp                                           ** Table for XN2 = 0.05
            0.04170      0.03300      0.03296
```

```
            0.94612     0.74864     0.74767
            1.53731     1.21643     1.21486
            1.87241     1.48158     1.47967
            2.32741     1.64874     1.64662
            2.22823     1.76313     1.76085
            2.33315     1.84615     1.84377
*keycomp                                          ** Table for XN2 = 0.10
            0.01078     0.00772     0.00771
            0.92407     0.66184     0.66062
            1.84613     1.32223     1.31979
            2.44543     1.75145     1.74823
            3.33460     2.03981     2.03606
            3.13385     2.24451     2.24038
            3.34631     2.39668     2.39227
*keycomp                                          ** Table for XN2 = 0.15
            0.00279     0.00181     0.00180
            0.90254     0.58510     0.58370
            2.21699     1.43723     1.43380
            3.19381     2.07048     2.06554
            4.77763     2.52364     2.51761
            4.40754     2.85733     2.85050
            4.79944     3.11139     3.10395
*keycomp                                          ** Table for XN2 = 0.20
            0.00072     0.00042     0.00042
            0.88151     0.51726     0.51574
            2.66234     1.56223     1.55764
            4.17122     2.44763     2.44044
            6.84514     3.12223     3.11306
            6.19891     3.63745     3.62677
            6.88360     4.03922     4.02736
*keycomp                                          ** Table for XN2 = 0.25
            0.00019     0.00010     0.00010
            0.86097     0.45729     0.45569
            3.19715     1.69811     1.69219
            5.44776     2.89347     2.88338
            9.80736     3.86280     3.84933
            8.71834     4.63058     4.61444
            9.87279     5.24374     5.22546

*kvtable 'C5-C6'
**    P =     2000        3000        4000      ** K-value tables for C5-C6:
**            -------     -------     -------
*keycomp                                          ** Table for XN2 = 0.00
            0.00167     0.00174     0.00197
            0.20350     0.21248     0.24001
            0.40127     0.41896     0.47324
            0.52621     0.54941     0.62059
            0.60883     0.63568     0.71804
            0.66691     0.69631     0.78653
            0.70979     0.74109     0.83710
*keycomp                                          ** Table for XN2 = 0.05
            4.78E-04    5.03E-04    5.82E-04
            0.14909     0.15698     0.18159
            0.33569     0.35346     0.40887
            0.46416     0.48873     0.56535
            0.55256     0.58181     0.67303
            0.61614     0.64876     0.75047
            0.66380     0.69894     0.80851
*keycomp                                          ** Table for XN2 = 0.10
            1.37E-04    1.45E-04    1.72E-04
            0.10923     0.11598     0.13740
            0.28082     0.29819     0.35325
            0.40942     0.43474     0.51502
            0.50149     0.53251     0.63084
            0.56924     0.60445     0.71606
            0.62079     0.65918     0.78090
*keycomp                                          ** Table for XN2 = 0.15
            3.92E-05    4.20E-05    5.10E-05
```

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```
             0.08002     0.08569     0.10396
             0.23493     0.25157     0.30520
             0.36114     0.38673     0.46917
             0.45515     0.48739     0.59130
             0.52592     0.56317     0.68324
             0.58056     0.62169     0.75423
*keycomp                                          ** Table for XN2 = 0.20
             1.12E-05    1.21E-05    1.51E-05
             0.05862     0.06331     0.07866
             0.19653     0.21224     0.26369
             0.31855     0.34401     0.42741
             0.41308     0.44609     0.55423
             0.48588     0.52471     0.65191
             0.54294     0.58633     0.72847
*keycomp                                          ** Table for XN2 = 0.25
             3.22E-06    3.51E-06    4.46E-06
             0.04295     0.04677     0.05951
             0.16441     0.17905     0.22782
             0.28099     0.30601     0.38936
             0.37490     0.40829     0.51949
             0.44890     0.48888     0.62203
             0.50776     0.55298     0.70359

*kvtable 'C7-C11'
**    P  =      2000        3000        4000     ** K-value tables for C7-C11:
**             -------     -------     -------
*keycomp                                          ** Table for XN2 = 0.00
             1.05E-11    1.26E-11    1.53E-11
             0.03791     0.04543     0.05524
             0.11775     0.14113     0.17160
             0.17641     0.21143     0.25709
             0.21709     0.26018     0.31636
             0.24630     0.29519     0.35893
             0.26812     0.32134     0.39073
*keycomp                                          ** Table for XN2 = 0.05
             2.21E-13    2.72E-13    3.41E-13
             0.02299     0.02833     0.03549
             0.08493     0.10465     0.13110
             0.13535     0.16676     0.20892
             0.17191     0.21182     0.26536
             0.19884     0.24500     0.30693
             0.21929     0.27019     0.33849
*keycomp                                          ** Table for XN2 = 0.10
             4.65E-15    5.89E-15    7.60E-15
             0.01395     0.01767     0.02281
             0.06126     0.07760     0.10016
             0.10384     0.13153     0.16978
             0.13614     0.17245     0.22259
             0.16053     0.20334     0.26247
             0.17935     0.22718     0.29323
*keycomp                                          ** Table for XN2 = 0.15
             9.78E-17    1.27E-16    1.69E-16
             0.00846     0.01102     0.01465
             0.04419     0.05754     0.07652
             0.07967     0.10374     0.13797
             0.10781     0.14039     0.18671
             0.12960     0.16877     0.22444
             0.14669     0.19101     0.25403
*keycomp                                          ** Table for XN2 = 0.20
             2.06E-18    2.75E-18    3.77E-18
             0.00513     0.00687     0.00942
             0.03187     0.04267     0.05846
             0.06112     0.08183     0.11212
             0.08538     0.11430     0.15661
             0.10463     0.14007     0.19193
             0.11997     0.16060     0.22006
*keycomp                                          ** Table for XN2 = 0.25
             4.33E-20    5.96E-20    8.41E-20
```

```
              0.00311    0.00429    0.00605
              0.02299    0.03164    0.04466
              0.04690    0.06454    0.09111
              0.06761    0.09305    0.13137
              0.08447    0.11626    0.16413
              0.09812    0.13504    0.19064


*kvtable 'C12-C17'
**   P  =     2000       3000       4000       ** K-value tables for C12-C17:
**          -------    -------    -------
*keycomp                                         ** Table for XN2 = 0.00
            8.52E-12   1.28E-11   1.70E-11
            0.001325   0.001987   0.002649
            0.008499   0.012749   0.016998
            0.017180   0.025769   0.034359
            0.024874   0.037312   0.049749
            0.031253   0.046880   0.06250603
            0.036488   0.054732   0.07297534
*keycomp                                         ** Table for XN2 = 0.05
            3.34E-13   5.27E-13   7.29E-13
            5.71E-04   9.01E-04   1.25E-03
            4.64E-03   7.32E-03   1.01E-02
            0.01025    0.01619    0.02239
            0.01555    0.02457    0.03397
            0.02012    0.03177    0.04394
            0.02396    0.03783    0.05232
*keycomp                                         ** Table for XN2 = 0.10
            1.31E-14   2.18E-14   3.12E-14
            2.46E-04   4.09E-04   5.86E-04
            2.53E-03   4.21E-03   6.03E-03
            6.11E-03   1.02E-02   1.46E-02
            9.73E-03   1.62E-02   2.32E-02
            0.01295    0.02154    0.03089
            0.01573    0.02615    0.03752
*keycomp                                         ** Table for XN2 = 0.15
            5.13E-16   8.98E-16   1.34E-15
            1.06E-04   1.85E-04   2.76E-04
            1.38E-03   2.42E-03   3.59E-03
            3.65E-03   6.39E-03   9.50E-03
            6.08E-03   1.06E-02   1.58E-02
            8.34E-03   1.46E-02   2.17E-02
            1.03E-02   1.81E-02   2.69E-02
*keycomp                                         ** Table for XN2 = 0.20
            2.01E-17   3.70E-17   5.72E-17
            4.56E-05   8.41E-05   1.30E-04
            7.53E-04   1.39E-03   2.14E-03
            2.18E-03   4.01E-03   6.19E-03
            3.80E-03   7.01E-03   1.08E-02
            5.37E-03   9.89E-03   1.53E-02
            6.78E-03   1.25E-02   1.93E-02
*keycomp                                         ** Table for XN2 = 0.25
            7.87E-19   1.53E-18   2.45E-18
            1.96E-05   3.81E-05   6.10E-05
            4.11E-04   7.97E-04   1.28E-03
            1.30E-03   2.52E-03   4.03E-03
            2.38E-03   4.62E-03   7.39E-03
            3.45E-03   6.71E-03   1.07E-02
            4.45E-03   8.64E-03   1.38E-02


*kvtable 'C18+'
**   P  =     2000       3000       4000       ** K-value tables for C18+:
**          -------    -------    -------
*keycomp                                         ** Table for XN2 = 0.00
            3.94E-17   1.33E-16   2.13E-16
            1.32E-05   4.49E-05   7.15E-05
            1.98E-04   6.72E-04   1.07E-03
            5.54E-04   1.88E-03   2.99E-03
            9.54E-04   3.23E-03   5.15E-03
```

```
                1.33E-03    4.52E-03    7.20E-03
                1.67E-03    5.67E-03    9.03E-03
*keycomp                                              ** Table for XN2 = 0.05
                6.33E-19    2.45E-18    4.11E-18
                3.88E-06    1.50E-05    2.52E-05
                7.80E-05    3.02E-04    5.06E-04
                2.44E-04    9.46E-04    1.59E-03
                4.46E-04    1.73E-03    2.89E-03
                6.46E-04    2.50E-03    4.20E-03
                8.31E-04    3.22E-03    5.40E-03
*keycomp                                              ** Table for XN2 = 0.10
                1.02E-20    4.50E-20    7.94E-20
                1.13E-06    5.02E-06    8.86E-06
                3.07E-05    1.36E-04    2.40E-04
                1.08E-04    4.76E-04    8.40E-04
                2.08E-04    9.22E-04    1.63E-03
                3.13E-04    1.39E-03    2.45E-03
                4.13E-04    1.83E-03    3.23E-03
*keycomp                                              ** Table for XN2 = 0.15
                1.63E-22    8.26E-22    1.53E-21
                3.32E-07    1.68E-06    3.12E-06
                1.21E-05    6.11E-05    1.13E-04
                4.74E-05    2.40E-04    4.45E-04
                9.74E-05    4.92E-04    9.14E-04
                1.52E-04    7.68E-04    1.43E-03
                2.05E-04    1.04E-03    1.93E-03
*keycomp                                              ** Table for XN2 = 0.20
                2.63E-24    1.52E-23    2.96E-23
                9.73E-08    5.62E-07    1.10E-06
                4.76E-06    2.75E-05    5.37E-05
                2.09E-05    1.21E-04    2.36E-04
                4.55E-05    2.63E-04    5.14E-04
                7.36E-05    4.25E-04    8.31E-04
                1.02E-04    5.90E-04    1.15E-03
*keycomp                                              ** Table for XN2 = 0.25
                4.22E-26    2.79E-25    5.73E-25
                2.85E-08    1.88E-07    3.87E-07
                1.87E-06    1.24E-05    2.54E-05
                9.19E-06    6.07E-05    1.25E-04
                2.13E-05    1.40E-04    2.89E-04
                3.57E-05    2.36E-04    4.85E-04
                5.07E-05    3.35E-04    6.89E-04


**  MOLECULAR WEIGHTS:
*cmm            0           ** WATER       use internal default value
                28.10       ** N2
                16.04       ** C1
                44.01       ** CO2
                39.62       ** C2-C4
                79.99       ** C5-C6
                118.51      ** C7-C11
                190.56      ** C12-C17
                358.96      ** C18+


**  CRITICAL PRESSURE (PSIA):
*pcrit          0           ** WATER       use internal default value
                493.1       ** N2
                666.4       ** C1
                1070.7      ** CO2
                649.3       ** C2-C4
                460.3       ** C5-C6
                440.2       ** C7-C11
                287.9       ** C12-C17
                156.1       ** C18+


**  CRITICAL TEMPERATURE (deg F):
*tcrit          0           ** WATER       use internal default value
                -232.47     ** N2
```

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```
              -116.67      ** C1
                87.93      ** CO2
               163.13      ** C2-C4
               415.53      ** C5-C6
               620.73      ** C7-C11
               939.73      ** C12-C17
              1173.33      ** C18+


**   REFERENCE CONDITIONS:
*prsr 14.7   *temr 60.0   *psurf 15.0   *tsurf 70.0


**   ENTHALPIES: MODEL DEFAULTS FOR FLUID EMPLOYED.
**   i.e  0.5  Btu/lb-F for components in the oil phase
**   and  0.25 Btu/lb-F for components in the gas phase.

**   LIQUID PHASE MASS DENSITIES AT REFERENCE CONDITIONS (LB/FT3):
*massden      0          ** WATER        ** use internal default value
             50.56       ** N2           ** apparent density from Katz
             18.72       ** C1           ** 18.72 (katz), 26.52 (prausnitz)
             51.19       ** CO2          ** apparent density from Katz
             27.87       ** C2-C4
             40.46       ** C5-C6
             49.46       ** C7-C11
             53.46       ** C12-C17
             56.02       ** C18+


**   LIQUID PHASE ISOTHERMAL COMPRESSIBILITIES (1/PSI):
*cp          0           ** WATER    use internal default value
             5.1e-05     ** N2
             6.0e-05     ** C1
             8.4e-05     ** CO2          ** pratz monograph pg. 209.
             5.4e-05     ** C2-C4
             1.2e-05     ** C5-C6
             5.7e-06     ** C7-C11
             4.4e-06     ** C12-C17
             3.8e-06     ** C18+


**   LIQUID PHASE THERMAL EXPANSION COEFFICIENT (FIRST COEF., 1/F):
*ct1          0.0e+00     ** WATER
              5.1e-04     ** N2
              5.1e-04     ** C1          ** <<ALL TO BE EVALUATED
              5.1e-04     ** CO2         **    FOR IN SITU COMBUSTION
              5.1e-04     ** C2-C4       **    RUNS>>
              5.1e-04     ** C5-C6
              5.1e-04     ** C7-C11
              5.1e-04     ** C12-C17
              5.1e-04     ** C18+


**   GAS PHASE VISCOSITIES:
*gviscor                          ** enable high gas density correction
**   (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avg       0            ** WATER    use internal default value
           1.6746E-16   ** N2
           7.4588E-09   ** C1
           2.0806E-15   ** CO2
           2.0806E-15   ** C2-C4
           1.7370E-15   ** C5-C6
           1.7370E-15   ** C7-C11
           1.7370E-15   ** C12-C17
           1.3250E-23   ** C18+


*bvg        0            ** WATER    use internal default value
            5.2260       ** N2
            2.2786       ** C1
            4.5559       ** CO2
            4.5559       ** C2-C4
            4.5832       ** C5-C6
```

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```
                 4.5832        ** C7-C11
                 4.5832        ** C12-C17
                 7.4030        ** C18+


**    LIQUID VISCOSITIES:
**    (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avisc          0             ** WATER    use internal default value
                0.0106140     ** N2
                0.0109660     ** C1
                0.0083353     ** CO2
                0.0084364     ** C2-C4
                0.0085699     ** C5-C6
                0.0172210     ** C7-C11
                0.0274550     ** C12-C17
                0.0989540     ** C18+


*bvisc          0             ** WATER    use internal default value
                2010.2        ** N2
                1982.1        ** C1
                1167.1        ** CO2
                1254.5        ** C2-C4
                2021.6        ** C5-C6
                2415.0        ** C7-C11 .
                2661.1        ** C12-C17
                3412.4        ** C18+



**    NO CHEMICAL REACTIONS SPECIFIED IN THIS DATA SET.
**surflash *kvalue


**    ============== ROCK-FLUID PROPERTIES  =====================
*rockfluid



*rpt 1       ** Rock type number of the following data.
**stone1     ** Stone's model I for three-phase rel perms (FASSIHI'S WORK).
**watwet     ** Specifying a water-wet system.

**    OIL-WATER RELATIVE PERMEABILITY:
*swt
**    Sw          Krw          Krow
**    -------      --------     --------
      0.0000       0.0000       1.0000
      1.0000       1.0000       0.0000


**  GAS-LIQUID RELATIVE PERMEABILITY:
*slt
**    Sl          Krg          Krog              ** From R. FASSIHI'S
**    -------      --------     --------          ** matching of fluegas
      0.2500       1.0000       0.00000           ** coreflood experiments.
      0.3000       0.8600       0.00010
      0.3500       0.7940       0.00034
      0.4000       0.7350       0.00125
      0.4500       0.6300       0.00430
      0.5000       0.5000       0.01170
      0.5500       0.4300       0.03410
      0.6000       0.3410       0.07940
      0.6500       0.2510       0.15800
      0.7000       0.2000       0.27100
      0.7500       0.1470       0.42900
      0.8000       0.0930       0.63100
      0.8500       0.0400       0.79400
      0.9000       0.0100       0.92600
      0.9500       0.0010       0.96200
      0.9750       0.0001       0.98100
      1.0000       0.0000       1.00000

*krtype *con 1  ** Above rock data assigned to all gridblocks.
```

```
**   ============== INITIAL CONDITIONS  ======================
*initial


*pres *con 2200.0         ** Initial core pressure, psia.
*sw   *con    0.00001     ** Initial core water saturation.
*so   *con    0.99999     ** Initial core oil saturation.
*sg   *con    0.00000     ** Initial core gas saturation.
*temp *con  190.0         ** Initial core temperature, deg F.

** INITIAL OIL PHASE MOLE FRACTIONS:
*molefrac *oil *con
              0.0000000    ** WATER
              0.0047405    ** N2
              0.3138985    ** C1
              0.0044390    ** CO2
              0.0557100    ** C2-C4
              0.0232272    ** C5-C6
              0.1959100    ** C7-C11
              0.1843430    ** C12-C17
              0.2176870    ** C18+

**   ============== NUMERICAL CONTROL  ======================
*numerical


**   ALL OF THESE CAN BE DEFAULTED.
*north 8  *newtoncyc 8  *itermax 15
*norm      press 15    satur .1    temp 40  y .1    x .1
*converge press .15  satur .002  temp .5  y .002  x .002

**   MAXIMUM NUMBER OF TIMESTEPS:
*maxsteps 1000               **  DEFAULT = 9999

*run
**   ============== RECURRENT DATA  ======================

*time           0.0              ** Starting time for this section, hrs.
   *dtwell      0.00024           ** Starting time step size, hrs.
   *dtmax       0.5               ** Maximum time step size, 0.024 hrs.

   *well 1 'INJECTOR'
   *injector 1          ** Well #1 is an injector.
   *operate *gas 788.0  ** Gas injection rate, scm3/hr
                        ** at core conditions = 6.45 cm3/hr.
   *incomp  *gas
              0.00    ** WATER
              0.85    ** N2          Composition of
              0.00    ** C1          injected gas.
              0.15    ** CO2
              0.00    ** C2-C4
              0.00    ** C5-C6
              0.00    ** C7-C11
              0.00    ** C12-C17
              0.00    ** C18+
   *tinjov  201.00      ** Temperature of the injected gas, deg F.
   *geometry *i -1 1 1 0  ** Linear pressure drop at beginning of tube.
   *perf *geo 1  ** i  j  k   Well #1 completed in block (1,1,1)
                    1  1  1


   *well 2 'PRODUCER'
   *producer 2          ** Well #2 is a producer.
   *operate *bhp 2200.0  ** Back pressure at producer is 3500 psia.
   *geometry *i -1 1 1 0  ** Linear pressure drop at tube end.
   *perf *geo 2  ** i  j   k   Well #2 completed in block (40,1,1).
                    40   1   1
*time        4.8         ** At 4 hrs change max step size to 0.24 hrs.
```

```
    *dtmax      1.0
*time          10.0
*time          24.0
*time          48.0           ** Pause for detailed printouts.
*time          72.0
*time          96.0
*time         120.0
*time        ·144.0
*time         168.0
    *stop
```

APPENDIX B-1

```
**   ============== INPUT/OUTPUT CONTROL  ========================
**   USE DEFAULT FILENAMES:
**filenames *output
**           *index-out
**           *main-results-out

**   SIMULATION RUN DESCRIPTION:
*title1 'West Hackberry Combustion Tube Test: HB-2'
*title2 'Initial Core Press. = 2000 psig, Core Temp. = 190 F'

**   INPUT AND OUTPUT UNITS:
*inunit  field except  1 1  ** hrs instead of days
              except 11 3  ** cm3 instead of bbls for well fluid volumes
*outunit field except  1 1  ** hrs instead of days
              except 11 3  ** cm3 instead of bbls for well fluid volumes

**   OUTPUT ITEMS AND FREQUENCY:
*outprn *grid pres          ** oil phase pressure
              so            ** oil saturation
              sg            ** gas saturation
              temp          ** temperature
              y             ** gas phase composition
              x             ** oil phase composition
              viso          ** oil viscosity
              masdeno       ** oil phase mass density
              solconc       ** component solid concentration

*outsrf special blkvar temp 0 1         ** T history, block 1
                blkvar temp 0 2         **    "       block 2
                blkvar temp 0 3         **    "       block 3
                blkvar temp 0 4         **    "       block 4
                blkvar temp 0 5         **    "       block 5
                blkvar temp 0 10        **    "       block 10
                blkvar temp 0.15        **    "       block 15
                blkvar temp 0 20        **    "       block 20
                blkvar so    0 1        ** So history, block 1
                blkvar so    0 10       ** So history, block 10
                blkvar solconc 11 1     ** Coke conc,  block 1
                blkvar solconc 11 10    ** Coke conc,  block 10
                blkvar y 10 22          ** y(oxygen), . "   22
                avgvar temp 0           ** average T in tube
                maxvar temp 0           ** maximum T in tube
                maxvar solconc 11       ** max coke conc in tube
                matbal reaction energy  ** net reaction energy
                tfront 400 forward      ** 400 deg front position
                tfront 600 forward      ** 600 deg front position
                tfront 400 backward     ** 400 deg backward front position

*outprn *well *all
*wprn *grid *time

*wsrf *grid *time
*wsrf *well 1

*wrst *time

** MOLECULAR WEIGHT OF COKE
*partclmlwt 14.3

**checkonly
*restart

**   ============== GRID AND CORE DESCRIPTION  ==================
```

```
**   22 BLOCKS IN THE CARTESIAN X(OR I) DIRECTION:
*grid *cart 1 1 22
      *kdir *down

**·Tube I.D. = 3.0 inches.  Cross-sectional area = pi*(d/2)**2
** = 0.049087 ft2 = L*L. So equivalent block size  is L = 0.221557 ft.
** Total tube length = 5.5 ft; block = 5.5/22 = 0.25 ft.
*di *con 0.221557
*dj *con 0.221557
*dk *con 0.25
**


**  ROCK (AND ASSOCIATED) PROPERTIES:
*por    *matrix   *con 0.355        ** porosity (adjusted from 0.375)
*permi *matrix   *con 1400          ** permeability, kx, md.
*permj *equalsi                     ** ky = kx.
*permk *equalsi                     ** kz = kx.
*cpor       0.0      ** rock compressibility, 1/psi.
*rockcp    35.0      ** rock volumetric heat capacity, Btu/ft3-F.
*cpc        4.06     ** coke heat capacity, Btu/lbmole-F.
*thconr     1.0      ** rock thermal cconductivity, Btu/ft-hr-F.
*thconw     0.36     ** water phase thermal conductivity, Btu/ft-hr-F.
*thcono     0.077    ** oil phase thermal conductivity, Btu/ft-hr-F.
*thcong     0.025    ** gas phase thermal conductivity, Btu/ft-hr-F.
*thconmix *simple    ** volume weighting of thermal conductivities.



**  ============== FLUID PROPERTIES  =====================



**  MODEL DESCRIPTION:
*model    11   ** total number of components {ncomp}.
          10   ** total number of components in oil, water,
          **     and gas phases {numy}.
           9   ** total number of components in water or oil phases {numx}.
           1   ** number of aqueous components {numw}.

**  COMPONENT NAMES:
*compname  'WATER' 'N2' 'C1' 'CO2' 'C2-C4' 'C5-C6'
           'C7-C11' 'C12-C17' 'C18+' 'O2'  'COKE'

** COMPOSITION DEPENDENT K-VALUE.TABLES:       <<TO EXPAND AND COMPLETE>>
*gasliqkv                     ** Gas/liquid k-value tables follow.
*kvtablim   2000   4000       ** Pressure range, psia. (i.e 2000,3000,4000)
            60     1000       ** Temperature range, F. (i.e. 60, 216,  373,
                      **                            530, 686, 843, 1000)
*kvkeycomp   'N2'            ** Key component for composition dependence.
             'X'            ** Phase for composition dependence.
             0.00           ** Lower composition limit, mole fraction.
             0.25           ** Upper ccomposition limit, mole fraction.


*kvtable 'N2'
**    P  =    2000       3000       4000    ** K-value tables for N2:
**            -------    -------    -------
*keycomp                                    ** Table for XN2 = 0.00
           17.36134   12.06577    9.56544
            6.03940    4.19725    3.32748
            5.08641    3.53495    2.80242
            4.74080    3.29475    2.61200
            4.56266    3.17096    2.51386
            4.45409    3.09550    2.45404
            4.38101    3.04471    2.41377
*keycomp                                    ** Table for XN2 = 0.05
           19.30202   13.23451   10.40193
            6.45636    4.42683    3.47936
            5.40303    3.70461    2.91171
            5.02276    3.44387    2.70678
            4.82716    3.30976    2.60138
```

```
            4.70809         3.22812         2.53720
            4.62800         3.17320         2.49404
*keycomp                                            ** Table for XN2 = 0.10
           21.45963        14.51645        11.31156
            6.90212         4.66896         3.63817
            5.73935         3.88241         3.02526
            5.32149         3.59974         2.80500
            5.10700         3.45465         2.69194
            4.97656         3.36642         2.62319
            4.88890         3.30712         2.57698
*keycomp                                            ** Table for XN2 = 0.15
           23.85843        15.92257        12.30074
            7.37865         4.92434         3.80422
            6.09661         4.06874         3.14324
            5.63799         3.76266         2.90679
            5.40305         3.60587         2.78566
            5.26035         3.51064         2.71209
            5.16452         3.44668         2.66268
*keycomp                                            ** Table for XN2 = 0.20
           26.52537        17.46489        13.37642
            7.88808         5.19368         3.97786
            6.47610         4.26401         3.26582
            5.97331         3.93296         3.01227
            5.71627         3.76372         2.88264
            5.56032         3.66104         2.80400
            5.45567         3.59214         2.75123
*keycomp                                            ** Table for XN2 = 0.25
           29.49042        19.15661        14.54617
            8.43268         5.47776         4.15942
            6.87922         4.46866         3.39318
            6.32858         4.11097         3.12158
            6.04764         3.92847         2.98300
            5.87740         3.81789         2.89903
            5.76324         3.74373         2.84272


*kvtable 'C1'
**   P  =      2000            3000            4000    ** K-value tables for C1:
**            -------         -------         -------
*keycomp                                            ** Table for XN2 = 0.00
            2.78885         2.10646         1.83944
            2.94163         2.22186         1.94021
            2.96828         2.24198         1.95778
            2.97934         2.25034         1.96508
            2.98540         2.25492         1.96908
            2.98923         2.25781         1.97160
            2.99186         2.25980         1.97334
*keycomp                                            ** Table for XN2 = 0.05
            2.78885         2.10646         1.83944
            2.94163         2.22186         1.94021
            2.96828         2.24198         1.95778
            2.97934         2.25034         1.96508
            2.98540         2.25492         1.96908
            2.98923         2.25781         1.97160
            2.99186         2.25980         1.97334
*keycomp                                            ** Table for XN2 = 0.10
            2.78885         2.10646         1.83944
            2.94163         2.22186         1.94021
            2.96828         2.24198         1.95778
            2.97934         2.25034         1.96508
            2.98540         2.25492         1.96908
            2.98923         2.25781         1.97160
            2.99186         2.25980         1.97334
*keycomp                                            ** Table for XN2 = 0.15
            2.78885         2.10646         1.83944
            2.94163         2.22186         1.94021
            2.96828         2.24198         1.95778
            2.97934         2.25034         1.96508
            2.98540         2.25492         1.96908
```

```
                2.98923        2.25781        1.97160
                2.99186        2.25980        1.97334
*keycomp                                              ** Table for XN2 = 0.20
                2.78885        2.10646        1.83944
                2.94163        2.22186        1.94021
                2.96828        2.24198        1.95778
                2.97934        2.25034        1.96508
                2.98540        2.25492        1.96908
                2.98923        2.25781        1.97160
                2.99186        2.25980        1.97334
*keycomp                                              ** Table for XN2 = 0.25
                2.78885        2.10646        1.83944
                2.94163        2.22186        1.94021
                2.96828        2.24198        1.95778
                2.97934        2.25034        1.96508
                2.98540        2.25492        1.96908
                2.98923        2.25781        1.97160
                2.99186        2.25980        1.97334


*kvtable 'CO2'
**    P  =      2000           3000           4000       ** K-value tables for CO2:
**             -------        -------        -------
*keycomp                                              ** Table for XN2 = 0.00
                1.40398        1.11397        1.02235
                1.54130        1.22292        1.12234
                1.56525        1.24192        1.13978
                1.57520        1.24981        1.14703
                1.58065        1.25414        1.15100
                1.58409        1.25687        1.15350
                1.58646        1.25875        1.15523
*keycomp                                              ** Table for XN2 = 0.05
                1.50213        1.13817        1.02686
                1.67998        1.27292        1.14843
                1.71133        1.29667        1.16987
                1.72438        1.30657        1.17879
                1.73154        1.31199        1.18368
                1.73606        1.31542        1.18677
                1.73918        1.31778        1.18890
*keycomp                                              ** Table for XN2 = 0.10
                1.60715        1.16290        1.03139
                1.83113        1.32497        1.17514
                1.87104        1.35385        1.20075
                1.88770        1.36590        1.21144
                1.89684        1.37251        1.21730
                1.90261        1.37669        1.22101
                1.90659        1.37957        1.22356
*keycomp                                              ** Table for XN2 = 0.15
                1.71950        1.18816        1.03594
                1.99589        1.37914        1.20246
                2.04566        1.41354        1.23244
                2.06648        1.42792        1.24499
                2.07791        1.43582        1.25187
                2.08514        1.44082        1.25623
                2.09013        1.44426        1.25923
*keycomp                                              ** Table for XN2 = 0.20
                1.83970        1.21397        1.04051
                2.17547        1.43554        1.23042
                2.23658        1.47586        1.26498
                2.26219        1.49276        1.27946
                2.27627        1.50206        1.28743
                2.28518        1.50793        1.29247
                2.29133        1.51199        1.29594
*keycomp                                              ** Table for XN2 = 0.25
                1.96831        1.24035        1.04510
                2.37121        1.49424        1.25902
                2.44531        1.54093        1.29837
                2.47644        1.56055        1.31490
                2.49357        1.57134        1.32399
```

```
              2.50441        1.57818        1.32975
              2.51189        1.58289        1.33372

*kvtable 'C2-C4'
**   P  =      2000           3000           4000      ** K-value tables for C2-C4:
**         -------        -------        -------
*keycomp                                             ** Table for XN2 = 0.00
              0.16126        0.14097        0.14087
              0.96869        0.84682        0.84619
              1.28015        1.11910        1.11827
              1.43366        1.25329        1.25236
              1.62444        1.33265        1.33166
              1.58431        1.38499        1.38396
              1.62674        1.42208        1.42102
*keycomp                                             ** Table for XN2 = 0.05
              0.04170        0.03300        0.03296
              0.94612        0.74864        0.74767
              1.53731        1.21643        1.21486
              1.87241        1.48158        1.47967
              2.32741        1.64874        1.64662
              2.22823        1.76313        1.76085
              2.33315        1.84615        1.84377
*keycomp                                             ** Table for XN2 = 0.10
              0.01078        0.00772        0.00771
              0.92407        0.66184        0.66062
              1.84613        1.32223        1.31979
              2.44543        1.75145        1.74823
              3.33460        2.03981        2.03606
              3.13385        2.24451        2.24038
              3.34631        2.39668        2.39227
*keycomp                                             ** Table for XN2 = 0.15
              0.00279        0.00181        0.00180
              0.90254        0.58510        0.58370
              2.21699        1.43723        1.43380
              3.19381        2.07048        2.06554
              4.77763        2.52364        2.51761
              4.40754        2.85733        2.85050
              4.79944        3.11139        3.10395
*keycomp                                             ** Table for XN2 = 0.20
              0.00072        0.00042        0.00042
              0.88151        0.51726        0.51574
              2.66234        1.56223        1.55764
              4.17122        2.44763        2.44044
              6.84514        3.12223        3.11306
              6.19891        3.63745        3.62677
              6.88360        4.03922        4.02736
*keycomp                                             ** Table for XN2 = 0.25
              0.00019        0.00010        0.00010
              0.86097        0.45729        0.45569
              3.19715        1.69811        1.69219
              5.44776        2.89347        2.88338
              9.80736        3.86280        3.84933
              8.71834        4.63058        4.61444
              9.87279        5.24374        5.22546

*kvtable 'C5-C6'
**   P  =      2000           3000           4000      ** K-value tables for C5-C6:
**         -------        -------        -------
*keycomp                                             ** Table for XN2 = 0.00
              0.00167        0.00174        0.00197
              0.20350        0.21248        0.24001
              0.40127        0.41896        0.47324
              0.52621        0.54941        0.62059
              0.60883        0.63568        0.71804
              0.66691        0.69631        0.78653
              0.70979        0.74109        0.83710
*keycomp                                             ** Table for XN2 = 0.05
              4.78E-04       5.03E-04       5.82E-04
```

```
           0.14909     0.15698     0.18159
           0.33569     0.35346     0.40887
           0.46416     0.48873     0.56535
           0.55256     0.58181     0.67303
           0.61614     0.64876     0.75047
           0.66380     0.69894     0.80851
*keycomp                                         ** Table for XN2 = 0.10

           1.37E-04    1.45E-04    1.72E-04
           0.10923     0.11598     0.13740
           0.28082     0.29819     0.35325
           0.40942     0.43474     0.51502
           0.50149     0.53251     0.63084
           0.56924     0.60445     0.71606
           0.62079     0.65918     0.78090
*keycomp                                         ** Table for XN2 = 0.15

           3.92E-05    4.20E-05    5.10E-05
           0.08002     0.08569     0.10396
           0.23493     0.25157     0.30520
           0.36114     0.38673     0.46917
           0.45515     0.48739     0.59130
           0.52592     0.56317     0.68324
           0.58056     0.62169     0.75423
*keycomp                                         ** Table for XN2 = 0.20

           1.12E-05    1.21E-05    1.51E-05
           0.05862     0.06331     0.07866
           0.19653     0.21224     0.26369
           0.31855     0.34401     0.42741
           0.41308     0.44609     0.55423
           0.48588     0.52471     0.65191
           0.54294     0.58633     0.72847
*keycomp                                         ** Table for XN2 = 0.25

           3.22E-06    3.51E-06    4.46E-06
           0.04295     0.04677     0.05951
           0.16441     0.17905     0.22782
           0.28099     0.30601     0.38936
           0.37490     0.40829     0.51949
           0.44890     0.48888     0.62203
           0.50776     0.55298     0.70359


*kvtable 'C7-C11'
**   P =     2000        3000        4000        ** K-value tables for C7-C11:
**           -------     -------     -------
*keycomp                                         ** Table for XN2 = 0.00
           1.05E-11    1.26E-11    1.53E-11
           0.03791     0.04543     0.05524
           0.11775     0.14113     0.17160
           0.17641     0.21143     0.25709
           0.21709     0.26018     0.31636
           0.24630     0.29519     0.35893
           0.26812     0.32134     0.39073
*keycomp                                         ** Table for XN2 = 0.05
           2.21E-13    2.72E-13    3.41E-13
           0.02299     0.02833     0.03549
           0.08493     0.10465     0.13110
           0.13535     0.16676     0.20892
           0.17191     0.21182     0.26536
           0.19884     0.24500     0.30693
           0.21929     0.27019     0.33849
*keycomp                                         ** Table for XN2 = 0.10
           4.65E-15    5.89E-15    7.60E-15
           0.01395     0.01767     0.02281
           0.06126     0.07760     0.10016
           0.10384     0.13153     0.16978
           0.13614     0.17245     0.22259
           0.16053     0.20334     0.26247
           0.17935     0.22718     0.29323
*keycomp                                         ** Table for XN2 = 0.15
           9.78E-17    1.27E-16    1.69E-16
```

```
                  0.00846    0.01102    0.01465
                  0.04419    0.05754    0.07652
                  0.07967    0.10374    0.13797
                  0.10781    0.14039    0.18671
                  0.12960    0.16877    0.22444
                  0.14669    0.19101    0.25403
*keycomp                                           ** Table for XN2 = 0.20
                  2.06E-18   2.75E-18   3.77E-18
                  0.00513    0.00687    0.00942
                  0.03187    0.04267    0.05846
                  0.06112    0.08183    0.11212
                  0.08538    0.11430    0.15661
                  0.10463    0.14007    0.19193
                  0.11997    0.16060    0.22006
*keycomp                                           ** Table for XN2 = 0.25
                  4.33E-20   5.96E-20   8.41E-20
                  0.00311    0.00429    0.00605
                  0.02299    0.03164    0.04466
                  0.04690    0.06454    0.09111
                  0.06761    0.09305    0.13137
                  0.08447    0.11626    0.16413
                  0.09812    0.13504    0.19064


*kvtable 'C12-C17'
**   P  =      2000       3000       4000      ** K-value tables for C12-C17:
**          -------    -------    -------
*keycomp                                           ** Table for XN2 = 0.00
                  8.52E-12   1.28E-11   1.70E-11
                  0.001325   0.001987   0.002649
                  0.008499   0.012749   0.016998
                  0.017180   0.025769   0.034359
                  0.024874   0.037312   0.049749
                  0.031253   0.046880   0.06250603
                  0.036488   0.054732   0.07297534
*keycomp                                           ** Table for XN2 = 0.05
                  3.34E-13   5.27E-13   7.29E-13
                  5.71E-04   9.01E-04   1.25E-03
                  4.64E-03   7.32E-03   1.01E-02
                  0.01025    0.01619    0.02239
                  0.01555    0.02457    0.03397
                  0.02012    0.03177    0.04394
                  0.02396    0.03783    0.05232
*keycomp                                           ** Table for XN2 = 0.10
                  1.31E-14   2.18E-14   3.12E-14
                  2.46E-04   4.09E-04   5.86E-04
                  2.53E-03   4.21E-03   6.03E-03
                  6.11E-03   1.02E-02   1.46E-02
                  9.73E-03   1.62E-02   2.32E-02
                  0.01295    0.02154    0.03089
                  0.01573    0.02615    0.03752
*keycomp                                           ** Table for XN2 = 0.15
                  5.13E-16   8.98E-16   1.34E-15
                  1.06E-04   1.85E-04   2.76E-04
                  1.38E-03   2.42E-03   3.59E-03
                  3.65E-03   6.39E-03   9.50E-03
                  6.08E-03   1.06E-02   1.58E-02
                  8.34E-03   1.46E-02   2.17E-02
                  1.03E-02   1.81E-02   2.69E-02
*keycomp                                           ** Table for XN2 = 0.20
                  2.01E-17   3.70E-17   5.72E-17
                  4.56E-05   8.41E-05   1.30E-04
                  7.53E-04   1.39E-03   2.14E-03
                  2.18E-03   4.01E-03   6.19E-03
                  3.80E-03   7.01E-03   1.08E-02
                  5.37E-03   9.89E-03   1.53E-02
                  6.78E-03   1.25E-02   1.93E-02
*keycomp                                           ** Table for XN2 = 0.25
                  7.87E-19   1.53E-18   2.45E-18
```

```
                1.96E-05   3.81E-05   6.10E-05
                4.11E-04   7.97E-04   1.28E-03
                1.30E-03   2.52E-03   4.03E-03
                2.38E-03   4.62E-03   7.39E-03
                3.45E-03   6.71E-03   1.07E-02
                4.45E-03   8.64E-03   1.38E-02


*kvtable 'C18+'
**    P  =    2000       3000       4000       ** K-value tables for C18+:
**           -------    -------    -------
*keycomp                                       ** Table for XN2 = 0.00
                3.94E-17   1.33E-16   2.13E-16
                1.32E-05   4.49E-05   7.15E-05
                1.98E-04   6.72E-04   1.07E-03
                5.54E-04   1.88E-03   2.99E-03
                9.54E-04   3.23E-03   5.15E-03
                1.33E-03   4.52E-03   7.20E-03
                1.67E-03   5.67E-03   .9.03E-03
*keycomp                                       ** Table for XN2 = 0.05
                6.33E-19   2.45E-18   4.11E-18
                3.88E-06   1.50E-05   2.52E-05
                7.80E-05   3.02E-04   5.06E-04
                2.44E-04   9.46E-04   1.59E-03
                4.46E-04   1.73E-03   2.89E-03
                6.46E-04   2.50E-03   4.20E-03
                8.31E-04   3.22E-03   5.40E-03
*keycomp                                       ** Table for XN2 = 0.10
                1.02E-20   4.50E-20   7.94E-20
                1.13E-06   5.02E-06   8.86E-06
                3.07E-05   1.36E-04   2.40E-04
                1.08E-04   4.76E-04   8.40E-04
                2.08E-04   9.22E-04   1.63E-03
                3.13E-04   1.39E-03   2.45E-03
                4.13E-04   1.83E-03   3.23E-03
*keycomp                                       ** Table for XN2 = 0.15
                1.63E-22   8.26E-22   1.53E-21
                3.32E-07   1.68E-06   3.12E-06
                1.21E-05   6.11E-05   1.13E-04
                4.74E-05   2.40E-04   4.45E-04
                9.74E-05   4.92E-04   9.14E-04
                1.52E-04   7.68E-04   1.43E-03
                2.05E-04   1.04E-03   1.93E-03
*keycomp                                       ** Table for XN2 = 0.20
                2.63E-24   1.52E-23   2.96E-23
                9.73E-08   5.62E-07   1.10E-06
                4.76E-06   2.75E-05   5.37E-05
                2.09E-05   1.21E-04   2.36E-04
                4.55E-05   2.63E-04   5.14E-04
                7.36E-05   4.25E-04   8.31E-04
                1.02E-04   5.90E-04   1.15E-03
*keycomp                                       ** Table for XN2 = 0.25
                4.22E-26   2.79E-25   5.73E-25
                2.85E-08   1.88E-07   3.87E-07
                1.87E-06   1.24E-05   2.54E-05
                9.19E-06   6.07E-05   1.25E-04
                2.13E-05   1.40E-04   2.89E-04
                3.57E-05   2.36E-04   4.85E-04
                5.07E-05   3.35E-04   6.89E-04


**   MOLECULAR WEIGHTS:
*cmm            0           ** WATER     use internal default value
              28.10         ** N2
              16.04         ** C1
              44.01         ** CO2
              39.62         ** C2-C4
              79.99         ** C5-C6
             118.51         ** C7-C11
```

```
              190.56        ** C12-C17
              358.96        ** C18+
               32.00        ** O2


**   CRITICAL PRESSURE (PSIA):
*pcrit           0          ** WATER       use internal default value
               493.1        ** N2
               666.4        ** C1
              1070.7        ** CO2
               649.3        ** C2-C4
               460.3        ** C5-C6
               440.2        ** C7-C11
               287.9        ** C12-C17
               156.1        ** C18+
               732.9        ** O2


**   CRITICAL TEMPERATURE (deg F):
*tcrit           0          ** WATER       use internal default value
              -232.47       ** N2
              -116.67       ** C1
                87.93       ** CO2
               163.13       ** C2-C4
               415.53       ** C5-C6
               620.73       ** C7-C11
               939.73       ** C12-C17
              1173.33       ** C18+
              -181.39       ** O2


**   ENTHALPIES: MODEL DEFAULTS FOR FLUID EMPLOYED.
**   i.e  0.5  Btu/lb-F for components in the oil phase
**   and  0.25 Btu/lb-F for components in the gas phase.


**   LIQUID PHASE MASS DENSITIES AT REFERENCE CONDITIONS (LB/FT3):
*massden      0          ** WATER      ** use internal default value
              50.56       ** N2         ** apparent density from Katz
              18.72       ** C1         ** 18.72 (katz), 26.52 (prausnitz)
              51.19       ** CO2        ** apparent density from Katz
              27.87       ** C2-C4
              40.46       ** C5-C6
              49.46       ** C7-C11
              53.46       ** C12-C17
              56.02       ** C18+


**   LIQUID PHASE ISOTHERMAL COMPRESSIBILITIES (1/PSI):
*cp           0             ** WATER    use internal default value
              5.1e-05       ** N2
              6.0e-05       ** C1
              8.4e-05       ** CO2              ** pratz monograph pg. 209.
              5.4e-05       ** C2-C4
              1.2e-05       ** C5-C6
              5.7e-06       ** C7-C11
              4.4e-06       ** C12-C17
              3.8e-06       ** C18+


**   LIQUID PHASE THERMAL EXPANSION COEFFICIENT (FIRST COEF., 1/F):
*ct1          0.0e+00       ** WATER
              5.1e-04       ** N2
              5.1e-04       ** C1         ** <<ALL TO BE EVALUATED
              5.1e-04       ** CO2        **    FOR IN SITU COMBUSTION
              5.1e-04       ** C2-C4      **    RUNS>>
              5.1e-04       ** C5-C6
              5.1e-04       ** C7-C11
              5.1e-04       ** C12-C17
              5.1e-04       ** C18+


**   GAS PHASE VISCOSITIES:
**gviscor                         ** enable high gas density correction
**   (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
```

```
*avg       0                 ** WATER     use internal default value
           1.6746E-16        ** N2
           7.4588E-09        ** C1
           2.0806E-15        ** CO2
           2.0806E-15        ** C2-C4
           1.7370E-15        ** C5-C6
           1.7370E-15 .      ** C7-C11
           1.7370E-15        ** C12-C17
           1.3250E-23        ** C18+
           1.6050E-04        ** O2

*bvg       0                 ** WATER     use internal default value
           5.2260            ** N2
           2.2786            ** C1
           4.5559            ** CO2
           4.5559            ** C2-C4
           4.5832            ** C5-C6
           4.5832            ** C7-C11
           4.5832            ** C12-C17
           7.4030            ** C18+
           0.7681            ** O2

**  LIQUID VISCOSITIES:
**  (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avisc     0                 ** WATER     use internal default value
           0.0106140         ** N2
           0.0109660         ** C1
           0.0083353         ** CO2
           0.0084364         ** C2-C4
           0.0085699         ** C5-C6
           0.0172210         ** C7-C11
           0.0274550         ** C12-C17
           0.0989540         ** C18+

*bvisc     0                 ** WATER     use internal default value
           2010.2            ** N2
           1982.1            ** C1
           1167.1            ** CO2
           1254.5            ** C2-C4
           2021.6            ** C5-C6
           2415.0            ** C7-C11
           2661.1            ** C12-C17
           3412.4            ** C18+

**  COKE DENSITY (lbmol/ft3)
*solden 4.4

**  REFERENCE CONDITIONS:
*prsr 14.7  *temr 60.0  *psurf 15.0  *tsurf 70.0

**  SURFACE FLASH:
**surflash *kvalue

**  COMBUSTION REACTIONS:

** Cracking: c12c17 -> coke + c7c11
**        h2o  n2   c1   co2  c2c4  c5c6   c7c11  c12c17  c18+  02   coke
*storeac  0    0    0    0    0     0      0      1       0     0    0
*stoprod  0    0    0    0    0     0      1.5276 0       0     0    0.6663
*freqfac  3.3512E+10           **
*eact     77534.0             ** Btu/lbmol
*renth    0.0                 ** Btu/lbmol


** Cracking:  C18+ -> coke + c7c11   (1g c18+ --> 0.05g coke + 0.95g c7c11)
**        h2o  n2   c1   co2  c2c4  c5c6   c7c11  c12c17  c18+  02   coke
*storeac  0    0    0    0    0     0      0      0       1     0    0
*stoprod  0    0    0    0    0     0      2.8774 0       0     0    1.255
```

```
*freqfac   3.3512E+10        **
*eact      77534.0           ** Btu/lbmol
*renth     0.0               ** Btu/lbmol


** C7-C11 burning:  c7-c11 + o2 -> h2o + co2 + energy
**         h2o   n2  c1    co2   c2c4  c5c6   c7c11  c12c17  c18+   02     coke
*storeac   0     0   0     0     0     0      1      0       0      12.062  0
*stoprod   7.145 0   0     8.541 0     0      0      0       0      0       0
*rorder    0     0   0     0     0     0      2.0    0       0      1.0     0
*freqfac   4.E+10           **
*eact      48600.0          ** Btu/lbmol
*renth     2.0409E+06       ** Btu/lbmol   (169200 Btu/lbmol 02)


** C12-C17 burning:  c12-c17 + o2 -> h2o + co2 + energy
**         h2o    n2  c1    co2    c2c4  c5c6   c7c11  c12c17  c18+   02     coke
*storeac   0      0   0     0      0     0      0      1       0      19.395  0
*stoprod   11.488 0   0     13.734 0     0      0      0       0      0       0
*rorder    0      0   0     0      0     0      0      2.0     0      1.0     0
*freqfac   4.E+10
*eact      48600.0          ** Btu/lbmol
*renth     3.2186E+06       ** Btu/lbmol   (169200 btu/lbmol 02)


** C18+ burning:  c18+ + o2 -> h2o + co2 + energy
**         h2o    n2  c1    co2    c2c4  c5c6   c7c11  c12c17  c18+   02     coke
*storeac   0      0   0     0      0     0      0      0       1      36.535  0
*stoprod   21.639 0   0     25.871 0     0      0      0       0      0       0
*rorder    0      0   0     0      0     0      0      0       2.0    1.0     0
*freqfac   4.E+10           **
*eact      48600.0          ** Btu/lbmol
*renth     6.1817E+06       ** Btu/lbmol   (169200 btu/lbmol 02)


** Coke burning:  coke + o2 -> h2o + co2 + energy
**         h2o     n2  c1   co2   c2c4  c5c6   c7c11  c12c17  c18+   02     coke
*storeac   0       0   0    0     0     0      0      0       0      1.455   1
*stoprod   0.9366  0   0    1     0     0      0      0       0      0       0
*freqfac   1.0E+08
*eact      14976            ** Btu/lbmol
*renth     246.2E+03        ** Btu/lbmol   (169200 btu/lbmol 02)


** =============== ROCK-FLUID PROPERTIES  =====================
*rockfluid

*rpt 1       ** Rock type number of the following data.
**stone1     ** Stone's model I for three-phase rel perms
**watwet     ** Specifying a water-wet system.

**  OIL-WATER RELATIVE PERMEABILITY:
*swt
**    Sw        Krw        Krow       Pcow
**  -------   --------   --------   --------
     0.00     0.0000     1.0000
     0.10     0.0010     0.7290
     0.20     0.0080     0.5120
     0.30     0.0270     0.3430
     0.40     0.0640     0.2160
     0.50     0.1250     0.1250
     0.60     0.2160     0.0640
     0.70     0.3430     0.0270
     0.80     0.5120     0.0080
     0.90     0.7290     0.0010
     1.00     1.0000     0.0000

** GAS-LIQUID RELATIVE PERMEABILITY:
```

```
*slt *noswc          **liquid saturation composed of oil only
**      Sl       Krg        Krog        Pcgo
**   -------   --------   --------    --------
        0.00    1.0000     0.0000      0.0000
        0.10    0.9000     0.0010      0.0000
        0.20    0.8000     0.0080      0.0000
        0.30    0.7000     0.0270      0.0000
        0.40    0.6000     0.0640      0.0000
        0.50    0.5000     0.1250      0.0000
        0.60    0.4000     0.2160      0.0000
        0.70    0.3000     0.3430      0.0000
        0.80    0.2000     0.5120      0.0000
        0.90    0.1000     0.7290      0.0000
        1.00    0.0000     1.0000      0.0000


**   OVERRIDE CRITICAL SATURATIONS IN TABLE:
*swr 0.340   *sorw 0.30   *sgr 0.00   *sorg 0.15


*krtype *con 1  ** Above rock data assigned to all gridblocks.


** ============== INITIAL CONDITIONS ======================
*initial

*pres *con    2000.0     ** Initial core pressure, psia.
*sw   *con     0.340     ** Initial core water saturation.
*so   *con     0.660     ** Initial core oil saturation. (0.660)
*sg   *con     0.000     ** Initial core gas saturation. (0.000)
*temp *con     190.0     ** Initial core temperature, deg F. (190.0)

** INITIAL OIL PHASE MOLE FRACTIONS:
*molefrac *oil *con
                0.000000      ** WATER
                0.000000      ** N2
                0.000000      ** C1
                0.000000      ** CO2
                0.010300      ** C2-C4
                0.038700      ** C5-C6
                0.308900      ** C7-C11
                0.346300      ** C12-C17
                0.295800      ** C18+


** ============== NUMERICAL CONTROL ======================
*numerical

** ALL OF THESE CAN BE DEFAULTED.
*north 8    *newtoncyc 8   *itermax 15
*north 10   *newtoncyc 10  *itermax 15

*unrelax -1

**norm      press 15   satur .1   temp 40   y 0.1   x 0.1
*norm       press 15   satur .1   temp 40   y 0.1   x 0.1

**converge press .15  satur .002  temp .5  y .002  x .002
*converge  press .15  satur .05   temp .5  y .05   x .05

**  MAXIMUM NUMBER OF TIMESTEPS:
*maxsteps 9999

*run
** ============== RECURRENT DATA ======================

*time -0.75   dtwell 0.001
```

```
well 1 'INJECTOR'  injector *mobweight 1
operate bhp 2120
incomp gas 0.0 1.0 8*0.0        ** nitrogen injection
tinjov 104                      ** injection temperature F.
perf 1 ** i  j  k  wi(gas)
          1  1  1  3.0e+03


well 2 'PRODUCER'  producer 2
operate bhp 2000.0
geometry k -1 1 1 0  ** Linear pressure drop at tube end
perf geo 2  ** i  j  k
              1  1  22

*tmpset *ijk 1 1 1:22    190.0    ** lose heat above 190 F
*uhtr   *ijk 1 1 1:22     -2.5    ** from zones 3 to 22.


*time -0.5

   injector *mobweight 1
   operate gas 150.0e+03        ** cm3/hr
   incomp gas  0.0 1.0 8*0.0    ** N2 injection
   tinjov 104                   ** injection temperature F.
   perf 1 ** i  j  k  wi(gas)
             1  1  1   5.0e+03


   *tmpset *ijk 1 1 1     650.0   ** heat zone 1 to 420 F.
             1 1 2     600.0   ** heat zone 2 to 500 F.
   *uhtr   *ijk 1 1 1       1.0
             1 1 2       1.5

*time 0.0                           ** start of air injection.

   injector *mobweight 1
   operate gas 250.0e+03            ** set air rate at 250 SLH.
   incomp gas 0.0 0.79 7*0.0 0.21   ** air injection
   tinjov 104.0                     ** air injection temperature F.
   perf 1 ** i  j  k  wi(gas)
             1  1  1   5.0e+03

   *tmpset *ijk 1 1 1      650.0
             1 1 2      600.0
             1 1 3:22    190.0
   *uhtr   *ijk 1 1 1        2.0
             1 1 2        1.5
             1 1 3:22      0.0    ** set rest of tube adiabatic.
*time 0.20
   *tmpset *ijk 1 1 1     650.0
             1 1 2     600.0      **
   *uhtr   *ijk 1 1 1       0.0    ** set zone 1 to adiabatic
             1 1 2       1.4

*time 0.4
   *tmpset *ijk 1 1 1     650.0
             1 1 2     600.0
   *uhtr   *ijk 1 1 1       0.0
             1 1 2       0.0    ** set zone 2 to adiabatic

*time 0.8
*time 1.8
*time 2.2
*time 2.4
*time 2.7
*time 3.25
   injector *mobweight 1
```

```
   operate gas 500.0e+03          ** set air rate at 500 SLH.
   incomp gas 0.0 0.79 7*0.0 0.21  ** air injection
   tinjov 104.0                    ** air injection temperature F.
   perf 1 ** i  j  k  wi(gas)
              1  1  1   5.0e+03
*time 3.4
*time 3.8
*time 4.2
*time 5.0
*time 5.7 stop
```

```
**  ============== INPUT/OUTPUT CONTROL  ======================
**  USE DEFAULT FILENAMES:
**filenames *output
**          *index-out
**          *main-results-out


**  SIMULATION RUN DESCRIPTION:
*title1 'West Hackberry Combustion Tube Test: HB-3'
*title2 'Initial Core Press. = 3500 psig, Core Temp. = 190 F'


**  INPUT AND OUTPUT UNITS:
*inunit  field except  1 1  ** hrs instead of days
                except 11 3  ** cm3 instead of bbls for well fluid volumes
*outunit field except  1 1  ** hrs instead of days
                except 11 3  ** cm3 instead of bbls for well fluid volumes


**  OUTPUT ITEMS AND FREQUENCY:
*outprn *grid pres       ** oil phase pressure
               so        ** oil saturation
               sg        ** gas saturation
               temp      ** temperature
               y         ** gas phase composition
               x         ** oil phase composition
               viso      ** oil viscosity
               masdeno   ** oil phase mass density
               solconc   ** component solid concentration


*outsrf special blkvar temp 0 1        ** T history, block 1
                blkvar temp 0 2        **     "      block 2
                blkvar temp 0 3        **     "      block 3
                blkvar temp 0 4        **     "      block 4
                blkvar temp 0 5        **     "      block 5
                blkvar temp 0 10       **     "      block 10
                blkvar temp 0 15       **     "      block 15
                blkvar temp 0 20       **     "      block 20
                blkvar so   0 1        ** So history, block 1
                blkvar so   0 10       ** So history, block 10
                blkvar solconc 11 1    ** Coke conc,  block 1
                blkvar solconc 11 10   ** Coke conc,  block 10
                blkvar y 10 22         ** y(oxygen),    "   22
                avgvar temp 0          ** average T in tube
                maxvar temp 0          ** maximum T in tube
                maxvar solconc 11      ** max coke conc in tube
                matbal reaction energy ** net reaction energy
                tfront 400 forward     ** 400 deg front position
                tfront 600 forward     ** 600 deg front position
                tfront 400 backward    ** 400 deg backward front position


*outprn *well *all
*wprn *grid *time

*wsrf *grid *time
*wsrf *well 1

*wrst *time

** MOLECULAR WEIGHT OF COKE
*partclmlwt 14.3

**checkonly
*restart


**  ============== GRID AND CORE DESCRIPTION  ==================
```

```
**  22 BLOCKS IN THE CARTESIAN X(OR I) DIRECTION:
*grid *cart 1 1 22
       *kdir *down


**  Tube I.D. = 3.0 inches.  Cross-sectional area = pi*(d/2)**2
**  = 0.049087 ft2 = L*L. So equivalent block size  is L = 0.221557 ft.
**  Total tube length = 5.5 ft; block = 5.5/22 = 0.25 ft.
*di *con 0.221557
*dj *con 0.221557
*dk *con 0.25
**


**   ROCK (AND ASSOCIATED) PROPERTIES:
*por    *matrix   *con 0.39        ** porosity (adjusted from 0.375)
*permi *matrix   *con 2200         ** permeability, kx, md.
*permj *equalsi                    ** ky = kx.
*permk *equalsi                    ** kz = kx.
*cpor       0.0        ** rock compressibility, 1/psi.
*rockcp    35.0        ** rock volumetric heat capacity, Btu/ft3-F.
*cpc        4.06       ** coke heat capacity, Btu/lbmole-F.
*thconr     1.0        ** rock thermal cconductivity, Btu/ft-hr-F.
*thconw     0.36       ** water phase thermal conductivity, Btu/ft-hr-F.
*thcono     0.077      ** oil phase thermal conductivity, Btu/ft-hr-F.
*thcong     0.025      ** gas phase thermal conductivity, Btu/ft-hr-F.
*thconmix *simple      ** volume weighting of thermal conductivities.


**   ============== FLUID PROPERTIES  =====================


**   MODEL DESCRIPTION:
*model    11    ** total number of components {ncomp}.
          10    ** total number of components in oil, water,
          **       and gas phases {numy}.
           9    ** total number of components in water or oil phases {numx}.
           1    ** number of aqueous components {numw}.

**   COMPONENT NAMES:
*compname   'WATER' 'N2' 'C1' 'CO2' 'C2-C4' 'C5-C6'
            'C7-C11' 'C12-C17' 'C18+' 'O2'  'COKE'

** COMPOSITION DEPENDENT K-VALUE TABLES:           <<TO EXPAND AND COMPLETE>>
*gasliqkv                  ** Gas/liquid k-value tables follow.
*kvtablim   2000   4000    ** Pressure range, psia. (i.e 2000,3000,4000)
             60   1000     ** Temperature range, F. (i.e. 60, 216,  373,
            **                             530, 686, 843, 1000)
*kvkeycomp   'N2'          ** Key component for composition dependence.
             'X'           ** Phase for composition dependence.
             0.00          ** Lower composition limit, mole fraction.
             0.25          ** Upper ccomposition limit, mole fraction.

*kvtable 'N2'
**   P =     2000       3000       4000     ** K-value tables for N2:
**           -------    -------    -------
*keycomp
                                            ** Table for XN2 = 0.00
          17.36134    12.06577   9.56544
           6.03940     4.19725   3.32748
           5.08641     3.53495   2.80242
           4.74080     3.29475   2.61200
           4.56266     3.17096   2.51386
           4.45409     3.09550   2.45404
           4.38101     3.04471   2.41377
*keycomp
                                            ** Table for XN2 = 0.05
          19.30202    13.23451  10.40193
           6.45636     4.42683   3.47936
           5.40303     3.70461   2.91171
           5.02276     3.44387   2.70678
           4.82716     3.30976   2.60138
```

```
         4.70809        3.22812         2.53720
         4.62800        3.17320         2.49404
*keycomp                                              ** Table for XN2 = 0.10
        21.45963       14.51645        11.31156
         6.90212        4.66896         3.63817
         5.73935        3.88241         3.02526
         5.32149        3.59974         2.80500
         5.10700        3.45465         2.69194
         4.97656        3.36642         2.62319
         4.88890        3.30712         2.57698
*keycomp                                              ** Table for XN2 = 0.15
        23.85843       15.92257        12.30074
         7.37865        4.92434         3.80422
         6.09661        4.06874         3.14324
         5.63799        3.76266         2.90679
         5.40305        3.60587         2.78566
         5.26035        3.51064         2.71209
         5.16452        3.44668         2.66268
*keycomp                                              ** Table for XN2 = 0.20
        26.52537       17.46489        13.37642
         7.88808        5.19368         3.97786
         6.47610        4.26401         3.26582
         5.97331        3.93296         3.01227
         5.71627        3.76372         2.88264
         5.56032        3.66104         2.80400
         5.45567        3.59214         2.75123
*keycomp                                              ** Table for XN2 = 0.25
        29.49042       19.15661        14.54617
         8.43268        5.47776         4.15942
         6.87922        4.46866         3.39318
         6.32858        4.11097         3.12158
         6.04764        3.92847         2.98300
         5.87740        3.81789         2.89903
         5.76324        3.74373         2.84272

*kvtable 'C1'
**    P =    2000           3000            4000    ** K-value tables for C1:
**           -------        -------         -------
*keycomp                                              ** Table for XN2 = 0.00
         2.78885        2.10646         1.83944
         2.94163        2.22186         1.94021
         2.96828        2.24198         1.95778
         2.97934        2.25034         1.96508
         2.98540        2.25492         1.96908
         2.98923        2.25781         1.97160
         2.99186        2.25980         1.97334
*keycomp                                              ** Table for XN2 = 0.05
         2.78885        2.10646         1.83944
         2.94163        2.22186         1.94021
         2.96828        2.24198         1.95778
         2.97934        2.25034         1.96508
         2.98540        2.25492         1.96908
         2.98923        2.25781         1.97160
         2.99186        2.25980         1.97334
*keycomp                                              ** Table for XN2 = 0.10
         2.78885        2.10646         1.83944
         2.94163        2.22186         1.94021
         2.96828        2.24198         1.95778
         2.97934        2.25034         1.96508
         2.98540        2.25492         1.96908
         2.98923        2.25781         1.97160
         2.99186        2.25980         1.97334
*keycomp                                              ** Table for XN2 = 0.15
         2.78885        2.10646         1.83944
         2.94163        2.22186         1.94021
         2.96828        2.24198         1.95778
         2.97934        2.25034         1.96508
         2.98540        2.25492         1.96908
```

```
                2.98923      2.25781      1.97160
                2.99186      2.25980      1.97334
*keycomp                                              ** Table for XN2 = 0.20
                2.78885      2.10646      1.83944
                2.94163      2.22186      1.94021
                2.96828      2.24198      1.95778
                2.97934      2.25034      1.96508
                2.98540      2.25492      1.96908
                2.98923      2.25781      1.97160
                2.99186      2.25980      1.97334
*keycomp                                              ** Table for XN2 = 0.25
                2.78885      2.10646      1.83944
                2.94163      2.22186      1.94021
                2.96828      2.24198      1.95778
                2.97934      2.25034      1.96508
                2.98540      2.25492      1.96908
                2.98923      2.25781      1.97160
                2.99186      2.25980      1.97334


*kvtable 'CO2'
**    P =       2000         3000         4000      ** K-value tables for CO2:
**              -------      -------      -------
*keycomp                                              ** Table for XN2 = 0.00
                1.40398      1.11397      1.02235
                1.54130      1.22292      1.12234
                1.56525      1.24192      1.13978
                1.57520      1.24981      1.14703
                1.58065      1.25414      1.15100
                1.58409      1.25687      1.15350
                1.58646      1.25875      1.15523
*keycomp                                              ** Table for XN2 = 0.05
                1.50213      1.13817      1.02686
                1.67998      1.27292      1.14843
                1.71133      1.29667      1.16987
                1.72438      1.30657      1.17879
                1.73154      1.31199      1.18368
                1.73606      1.31542      1.18677
                1.73918      1.31778      1.18890
*keycomp                                              ** Table for XN2 = 0.10
                1.60715      1.16290      1.03139
                1.83113      1.32497      1.17514
                1.87104      1.35385      1.20075
                1.88770      1.36590      1.21144
                1.89684      1.37251      1.21730
                1.90261      1.37669      1.22101
                1.90659      1.37957      1.22356
*keycomp                                              ** Table for XN2 = 0.15
                1.71950      1.18816      1.03594
                1.99589      1.37914      1.20246
                2.04566      1.41354      1.23244
                2.06648      1.42792      1.24499
                2.07791      1.43582      1.25187
                2.08514      1.44082      1.25623
                2.09013      1.44426      1.25923
*keycomp                                              ** Table for XN2 = 0.20
                1.83970      1.21397      1.04051
                2.17547      1.43554      1.23042
                2.23658      1.47586      1.26498
                2.26219      1.49276      1.27946
                2.27627      1.50206      1.28743
                2.28518      1.50793      1.29247
                2.29133      1.51199      1.29594
*keycomp                                              ** Table for XN2 = 0.25
                1.96831      1.24035      1.04510
                2.37121      1.49424      1.25902
                2.44531      1.54093      1.29837
                2.47644      1.56055      1.31490
                2.49357      1.57134      1.32399
```

	2.50441	1.57818	1.32975
	2.51189	1.58289	1.33372

*kvtable 'C2-C4'
| ** P = | 2000 | 3000 | 4000 | ** K-value tables for C2-C4: |
| ** | ------- | ------- | ------- | |

*keycomp   ** Table for XN2 = 0.00

	0.16126	0.14097	0.14087
	0.96869	0.84682	0.84619
	1.28015	1.11910	1.11827
	1.43366	1.25329	1.25236
	1.62444	1.33265	1.33166
	1.58431	1.38499	1.38396
	1.62674	1.42208	1.42102

*keycomp   ** Table for XN2 = 0.05

	0.04170	0.03300	0.03296
	0.94612	0.74864	0.74767
	1.53731	1.21643	1.21486
	1.87241	1.48158	1.47967
	2.32741	1.64874	1.64662
	2.22823	1.76313	1.76085
	2.33315	1.84615	1.84377

*keycomp   ** Table for XN2 = 0.10

	0.01078	0.00772	0.00771
	0.92407	0.66184	0.66062
	1.84613	1.32223	1.31979
	2.44543	1.75145	1.74823
	3.33460	2.03981	2.03606
	3.13385	2.24451	2.24038
	3.34631	2.39668	2.39227

*keycomp   ** Table for XN2 = 0.15

	0.00279	0.00181	0.00180
	0.90254	0.58510	0.58370
	2.21699	1.43723	1.43380
	3.19381	2.07048	2.06554
	4.77763	2.52364	2.51761
	4.40754	2.85733	2.85050
	4.79944	3.11139	3.10395

*keycomp   ** Table for XN2 = 0.20

	0.00072	0.00042	0.00042
	0.88151	0.51726	0.51574
	2.66234	1.56223	1.55764
	4.17122	2.44763	2.44044
	6.84514	3.12223	3.11306
	6.19891	3.63745	3.62677
	6.88360	4.03922	4.02736

*keycomp   ** Table for XN2 = 0.25

	0.00019	0.00010	0.00010
	0.86097	0.45729	0.45569
	3.19715	1.69811	1.69219
	5.44776	2.89347	2.88338
	9.80736	3.86280	3.84933
	8.71834	4.63058	4.61444
	9.87279	5.24374	5.22546

*kvtable 'C5-C6'
| ** P = | 2000 | 3000 | 4000 | ** K-value tables for C5-C6: |
| ** | ------- | ------- | ------- | |

*keycomp   ** Table for XN2 = 0.00

	0.00167	0.00174	0.00197
	0.20350	0.21248	0.24001
	0.40127	0.41896	0.47324
	0.52621	0.54941	0.62059
	0.60883	0.63568	0.71804
	0.66691	0.69631	0.78653
	0.70979	0.74109	0.83710

*keycomp   ** Table for XN2 = 0.05

	4.78E-04	5.03E-04	5.82E-04

```
          0.14909    0.15698    0.18159
          0.33569    0.35346    0.40887
          0.46416    0.48873    0.56535
          0.55256    0.58181    0.67303
          0.61614    0.64876    0.75047
          0.66380    0.69894    0.80851
*keycomp                                    ** Table for XN2 = 0.10
          1.37E-04   1.45E-04   1.72E-04
          0.10923    0.11598    0.13740
          0.28082    0.29819    0.35325
          0.40942    0.43474    0.51502
          0.50149    0.53251    0.63084
          0.56924    0.60445    0.71606
          0.62079    0.65918    0.78090
*keycomp                                    ** Table for XN2 = 0.15
          3.92E-05   4.20E-05   5.10E-05
          0.08002    0.08569    0.10396
          0.23493    0.25157    0.30520
          0.36114    0.38673    0.46917
          0.45515    0.48739    0.59130
          0.52592    0.56317    0.68324
          0.58056    0.62169    0.75423
*keycomp                                    ** Table for XN2 = 0.20
          1.12E-05   1.21E-05   1.51E-05
          0.05862    0.06331    0.07866
          0.19653    0.21224    0.26369
          0.31855    0.34401    0.42741
          0.41308    0.44609    0.55423
          0.48588    0.52471    0.65191
          0.54294    0.58633    0.72847
*keycomp                                    ** Table for XN2 = 0.25
          3.22E-06   3.51E-06   4.46E-06
          0.04295    0.04677    0.05951
          0.16441    0.17905    0.22782
          0.28099    0.30601    0.38936
          0.37490    0.40829    0.51949
          0.44890    0.48888    0.62203
          0.50776    0.55298    0.70359

*kvtable 'C7-C11'
**    P  =    2000       3000       4000    ** K-value tables for C7-C11:
**            -------    -------    -------
*keycomp                                    ** Table for XN2 = 0.00
          1.05E-11   1.26E-11   1.53E-11
          0.03791    0.04543    0.05524
          0.11775    0.14113    0.17160
          0.17641    0.21143    0.25709
          0.21709    0.26018    0.31636
          0.24630    0.29519    0.35893
          0.26812    0.32134    0.39073
*keycomp                                    ** Table for XN2 = 0.05
          2.21E-13   2.72E-13   3.41E-13
          0.02299    0.02833    0.03549
          0.08493    0.10465    0.13110
          0.13535    0.16676    0.20892
          0.17191    0.21182    0.26536
          0.19884    0.24500    0.30693
          0.21929    0.27019    0.33849
*keycomp                                    ** Table for XN2 = 0.10
          4.65E-15   5.89E-15   7.60E-15
          0.01395    0.01767    0.02281
          0.06126    0.07760    0.10016
          0.10384    0.13153    0.16978
          0.13614    0.17245    0.22259
          0.16053    0.20334    0.26247
          0.17935    0.22718    0.29323
*keycomp                                    ** Table for XN2 = 0.15
          9.78E-17   1.27E-16   1.69E-16
```
C-96

```
          0.00846    0.01102    0.01465
          0.04419    0.05754    0.07652
          0.07967    0.10374    0.13797
          0.10781    0.14039    0.18671
          0.12960    0.16877    0.22444
          0.14669    0.19101    0.25403
*keycomp                                    ** Table for XN2 = 0.20
          2.06E-18   2.75E-18   3.77E-18
          0.00513    0.00687    0.00942
          0.03187    0.04267    0.05846
          0.06112    0.08183    0.11212
          0.08538    0.11430    0.15661
          0.10463    0.14007    0.19193
          0.11997    0.16060    0.22006
*keycomp                                    ** Table for XN2 = 0.25
          4.33E-20   5.96E-20   8.41E-20
          0.00311    0.00429    0.00605
          0.02299    0.03164    0.04466
          0.04690    0.06454    0.09111
          0.06761    0.09305    0.13137
          0.08447    0.11626    0.16413
          0.09812    0.13504    0.19064


*kvtable 'C12-C17'
**   P =     2000       3000       4000     ** K-value tables for C12-C17:
**           -------    -------    -------
*keycomp                                    ** Table for XN2 = 0.00
          8.52E-12   1.28E-11   1.70E-11
          0.001325   0.001987   0.002649
          0.008499   0.012749   0.016998
          0.017180   0.025769   0.034359
          0.024874   0.037312   0.049749
          0.031253   0.046880   0.06250603
          0.036488   0.054732   0.07297534
*keycomp                                    ** Table for XN2 = 0.05
          3.34E-13   5.27E-13   7.29E-13
          5.71E-04   9.01E-04   1.25E-03
          4.64E-03   7.32E-03   1.01E-02
          0.01025    0.01619    0.02239
          0.01555    0.02457    0.03397
          0.02012    0.03177    0.04394
          0.02396    0.03783    0.05232
*keycomp                                    ** Table for XN2 = 0.10
          1.31E-14   2.18E-14   3.12E-14
          2.46E-04   4.09E-04   5.86E-04
          2.53E-03   4.21E-03   6.03E-03
          6.11E-03   1.02E-02   1.46E-02
          9.73E-03   1.62E-02   2.32E-02
          0.01295    0.02154    0.03089
          0.01573    0.02615    0.03752
*keycomp                                    ** Table for XN2 = 0.15
          5.13E-16   8.98E-16   1.34E-15
          1.06E-04   1.85E-04   2.76E-04
          1.38E-03   2.42E-03   3.59E-03
          3.65E-03   6.39E-03   9.50E-03
          6.08E-03   1.06E-02   1.58E-02
          8.34E-03   1.46E-02   2.17E-02
          1.03E-02   1.81E-02   2.69E-02
*keycomp                                    ** Table for XN2 = 0.20
          2.01E-17   3.70E-17   5.72E-17
          4.56E-05   8.41E-05   1.30E-04
          7.53E-04   1.39E-03   2.14E-03
          2.18E-03   4.01E-03   6.19E-03
          3.80E-03   7.01E-03   1.08E-02
          5.37E-03   9.89E-03   1.53E-02
          6.78E-03   1.25E-02   1.93E-02
*keycomp                                    ** Table for XN2 = 0.25
          7.87E-19   1.53E-18   2.45E-18
```

```
                  1.96E-05    3.81E-05   6.10E-05
                  4.11E-04    7.97E-04   1.28E-03
                  1.30E-03    2.52E-03   4.03E-03
                  2.38E-03    4.62E-03   7.39E-03
                  3.45E-03    6.71E-03   1.07E-02
                  4.45E-03    8.64E-03   1.38E-02

*kvtable 'C18+'
**    P  =      2000        3000       4000      ** K-value tables for C18+:
**            -------     -------    -------
*keycomp                                          ** Table for XN2 = 0.00
                  3.94E-17    1.33E-16   2.13E-16
                  1.32E-05    4.49E-05   7.15E-05
                  1.98E-04    6.72E-04   1.07E-03
                  5.54E-04    1.88E-03   2.99E-03
                  9.54E-04    3.23E-03   5.15E-03
                  1.33E-03    4.52E-03   7.20E-03
                  1.67E-03    5.67E-03   9.03E-03
*keycomp                                          ** Table for XN2 = 0.05
                  6.33E-19    2.45E-18   4.11E-18
                  3.88E-06    1.50E-05   2.52E-05
                  7.80E-05    3.02E-04   5.06E-04
                  2.44E-04    9.46E-04   1.59E-03
                  4.46E-04    1.73E-03   2.89E-03
                  6.46E-04    2.50E-03   4.20E-03
                  8.31E-04    3.22E-03   5.40E-03
*keycomp                                          ** Table for XN2 = 0.10
                  1.02E-20    4.50E-20   7.94E-20
                  1.13E-06    5.02E-06   8.86E-06
                  3.07E-05    1.36E-04   2.40E-04
                  1.08E-04    4.76E-04   8.40E-04
                  2.08E-04    9.22E-04   1.63E-03
                  3.13E-04    1.39E-03   2.45E-03
                  4.13E-04    1.83E-03   3.23E-03
*keycomp                                          ** Table for XN2 = 0.15
                  1.63E-22    8.26E-22   1.53E-21
                  3.32E-07    1.68E-06   3.12E-06
                  1.21E-05    6.11E-05   1.13E-04
                  4.74E-05    2.40E-04   4.45E-04
                  9.74E-05    4.92E-04   9.14E-04
                  1.52E-04    7.68E-04   1.43E-03
                  2.05E-04    1.04E-03   1.93E-03
*keycomp                                          ** Table for XN2 = 0.20
                  2.63E-24    1.52E-23   2.96E-23
                  9.73E-08    5.62E-07   1.10E-06
                  4.76E-06    2.75E-05   5.37E-05
                  2.09E-05    1.21E-04   2.36E-04
                  4.55E-05    2.63E-04   5.14E-04
                  7.36E-05    4.25E-04   8.31E-04
                  1.02E-04    5.90E-04   1.15E-03
*keycomp                                          ** Table for XN2 = 0.25
                  4.22E-26    2.79E-25   5.73E-25
                  2.85E-08    1.88E-07   3.87E-07
                  1.87E-06    1.24E-05   2.54E-05
                  9.19E-06    6.07E-05   1.25E-04
                  2.13E-05    1.40E-04   2.89E-04
                  3.57E-05    2.36E-04   4.85E-04
                  5.07E-05    3.35E-04   6.89E-04


**   MOLECULAR WEIGHTS:
*cmm             0          ** WATER      use internal default value
                 28.10      ** N2
                 16.04      ** C1
                 44.01      ** CO2
                 39.62      ** C2-C4
                 79.99      ** C5-C6
                118.51      ** C7-C11
```

```
              190.56        ** C12-C17
              358.96        ** C18+
               32.00        ** 02


**  CRITICAL PRESSURE (PSIA):
*pcrit          0           ** WATER      use internal default value
              493.1         ** N2
              666.4         ** C1
             1070.7         ** CO2
              649.3         ** C2-C4
              460.3         ** C5-C6
              440.2         ** C7-C11
              287.9         ** C12-C17
              156.1         ** C18+
              732.9         ** 02


**  CRITICAL TEMPERATURE (deg F):
*tcrit          0           ** WATER      use internal default value
             -232.47        ** N2
             -116.67        ** C1
               87.93        ** CO2
              163.13        ** C2-C4
              415.53        ** C5-C6
              620.73        ** C7-C11
             939.73         ** C12-C17
             1173.33        ** C18+
             -181.39        ** 02


**  ENTHALPIES: MODEL DEFAULTS FOR FLUID EMPLOYED.
**  i.e  0.5  Btu/lb-F for components in the oil phase
**  and  0.25 Btu/lb-F for components in the gas phase.

**  LIQUID PHASE MASS DENSITIES AT REFERENCE CONDITIONS (LB/FT3):
*massden        0           ** WATER       ** use internal default value
               50.56        ** N2          ** apparent density from Katz
               18.72        ** C1          ** 18.72 (katz), 26.52 (prausnitz)
               51.19        ** CO2         ** apparent density from Katz
               27.87        ** C2-C4
               40.46        ** C5-C6
               49.46        ** C7-C11
               53.46        ** C12-C17
               56.02        ** C18+


**  LIQUID PHASE ISOTHERMAL COMPRESSIBILITIES (1/PSI):
*cp             0           ** WATER    use internal default value
              5.1e-05       ** N2
              6.0e-05       ** C1
              8.4e-05       ** CO2         ** pratz monograph pg. 209.
              5.4e-05       ** C2-C4
              1.2e-05       ** C5-C6
              5.7e-06       ** C7-C11
              4.4e-06       ** C12-C17
              3.8e-06       ** C18+


**  LIQUID PHASE THERMAL EXPANSION COEFFICIENT (FIRST COEF., 1/F):
*ct1           0.0e+00      ** WATER
              5.1e-04       ** N2
              5.1e-04       ** C1          ** <<ALL TO BE EVALUATED
              5.1e-04       ** CO2         **    FOR IN SITU COMBUSTION
              5.1e-04       ** C2-C4       **    RUNS>>
              5.1e-04       ** C5-C6
              5.1e-04       ** C7-C11
              5.1e-04       ** C12-C17
              5.1e-04       ** C18+


**  GAS PHASE VISCOSITIES:
**gviscor                            ** enable high gas density correction
**  (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
```

```
*avg         0              ** WATER    use internal default value
            1.6746E-16      ** N2
            7.4588E-09      ** C1
            2.0806E-15      ** CO2
            2.0806E-15      ** C2-C4
            1.7370E-15      ** C5-C6
            1.7370E-15      ** C7-C11
            1.7370E-15      ** C12-C17
            1.3250E-23      ** C18+
            1.6050E-04      ** O2

*bvg         0              ** WATER    use internal default value
            5.2260          ** N2
            2.2786          ** C1
            4.5559          ** CO2
            4.5559          ** C2-C4
            4.5832          ** C5-C6
            4.5832          ** C7-C11
            4.5832          ** C12-C17
            7.4030          ** C18+
            0.7681          ** O2

**  LIQUID VISCOSITIES:
**  (COEFFICIENTTS FITTED FROM REZA FASSIHI'S WORK)
*avisc       0              ** WATER    use internal default value
            0.0106140       ** N2
            0.0109660       ** C1
            0.0083353       ** CO2
            0.0084364       ** C2-C4
            0.0085699       ** C5-C6
            0.0172210       ** C7-C11
            0.0274550       ** C12-C17
            0.0989540       ** C18+

*bvisc       0              ** WATER    use internal default value
            2010.2          ** N2
            1982.1          ** C1
            1167.1          ** CO2
            1254.5          ** C2-C4
            2021.6          ** C5-C6
            2415.0          ** C7-C11
            2661.1          ** C12-C17
            3412.4          ** C18+

**  COKE DENSITY (lbmol/ft3)
*solden 4.4

**  REFERENCE CONDITIONS:
*prsr 14.7  *temr 60.0  *psurf 15.0  *tsurf 70.0

**  SURFACE FLASH:
**surflash *kvalue

**  COMBUSTION REACTIONS:

** Cracking:  c12c17 -> coke + c7c11
**        h2o   n2   c1   co2   c2c4   c5c6   c7c11   c12c17   c18+   o2   coke
*storeac   0    0    0    0     0      0      0       1        0      0    0
*stoprod   0    0    0    0     0      0      1.5276  0        0      0    0.6663
*freqfac  3.3512E+10        **
*eact     77534.0           ** Btu/lbmol
*renth    0.0               ** Btu/lbmol


** Cracking:  C18+ -> coke + c7c11  (1g c18+ --> 0.05g coke + 0.95g c7c11)
**        h2o   n2   c1   co2   c2c4   c5c6   c7c11   c12c17   c18+   o2   coke
*storeac   0    0    0    0     0      0      0       0        1      0    0
*stoprod   0    0    0    0     0      0      2.8774  0        0      0    1.255
```

C–100

```
*freqfac   3.3512E+10        **
*eact      77534.0           ** Btu/lbmol
*renth     0.0               ** Btu/lbmol


** C7-C11 burning:  c7-c11 + o2 -> h2o + co2 + energy
**         h2o    n2  c1    co2   c2c4  c5c6   c7c11  c12c17  c18+   o2      coke
*storeac   0      0   0     0     0     0      1       0      0      12.062    0
*stoprod   7.145  0   0     8.541 0     0      0       0      0      0         0
*rorder    0      0   0     0     0     0      2.0     0      0      1.0       0
*freqfac   4.E+10      **
*eact      48600.0      ** Btu/lbmol
*renth     1.2245E+06  ** Btu/lbmol  (0.6*169200 Btu/lbmol O2)


** C12-C17 burning:  c12-c17 + o2 -> h2o + co2 + energy
**         h2o     n2  c1    co2    c2c4  c5c6   c7c11  c12c17  c18+   o2      coke
*storeac   0       0   0     0      0     0      0       1      0      19.395    0
*stoprod   11.488  0   0     13.734 0     0      0       0      0      0         0
*rorder    0       0   0     0      0     0      0       2.0    0      1.0       0
*freqfac   4.E+10
*eact      48600.0      ** Btu/lbmol
*renth     1.9689E+06  ** Btu/lbmol  (0.6*169200 btu/lbmol O2)


** C18+ burning:  c18+ + o2 -> h2o + co2 + energy
**         h2o     n2  c1    co2     c2c4  c5c6   c7c11  c12c17  c18+   o2      coke
*storeac   0       0   0     0       0     0      0       0      1      36.535    0
*stoprod   21.639  0   0     25.871  0     0      0       0      0      0         0
*rorder    0       0   0     0       0     0      0       0      2.0    1.0       0
*freqfac   4.E+10      ** 5E+10
*eact      48600.0      ** Btu/lbmol
*renth     3.7090E+06  ** Btu/lbmol  (0.6*169200 btu/lbmol O2)


** Coke burning:  coke + o2 -> h2o + co2 + energy
**         h2o     n2  c1    co2    c2c4  c5c6   c7c11  c12c17  c18+   o2      coke
*storeac   0       0   0     0      0     0      0       0      0      1.455    1
*stoprod   0.9366  0   0     1      0     0      0       0      0      0        0
*freqfac   1.0E+08
*eact      14976        ** Btu/lbmol
*renth     246.2E+03   ** Btu/lbmol   (169200 btu/lbmol O2)
```

```
** ============== ROCK-FLUID PROPERTIES  =====================
*rockfluid

*rpt 1        ** Rock type number of the following data.
**stone1      ** Stone's model I for three-phase rel perms
**watwet      ** Specifying a water-wet system.

**  OIL-WATER RELATIVE PERMEABILITY:
*swt
**    Sw        Krw         Krow       Pcow
**  -------   --------    --------    --------
     0.00      0.0000      1.0000
     0.10      0.0010      0.7290
     0.20      0.0080      0.5120
     0.30      0.0270      0.3430
     0.40      0.0640      0.2160
     0.50      0.1250      0.1250
     0.60      0.2160      0.0640
     0.70      0.3430      0.0270
     0.80      0.5120      0.0080
     0.90      0.7290      0.0010
     1.00      1.0000      0.0000

** GAS-LIQUID RELATIVE PERMEABILITY:
```

```
*slt *noswc          **liquid saturation composed of oil only
**      Sl        Krg        Krog        Pcgo
**   -------    --------    --------    --------
       0.00     1.0000      0.0000      0.0000
       0.10     0.9000      0.0010      0.0000
       0.20     0.8000      0.0080      0.0000
       0.30     0.7000      0.0270      0.0000
       0.40     0.6000      0.0640      0.0000
       0.50     0.5000      0.1250      0.0000
       0.60     0.4000      0.2160      0.0000
       0.70     0.3000      0.3430      0.0000
       0.80     0.2000      0.5120      0.0000
       0.90     0.1000      0.7290      0.0000
       1.00     0.0000      1.0000      0.0000

**   OVERRIDE CRITICAL SATURATIONS IN TABLE:
**swr 0.272  *sorw 0.30   *sgr 0.05  *sorg 0.08
*swr 0.272  *sorw 0.30   *sgr 0.05  *sorg 0.08


*krtype *con 1  ** Above rock data assigned to all gridblocks.

**  =============== INITIAL CONDITIONS  =======================
*initial

*pres *con    3500.0    ** Initial core pressure, psia.
*sw   *con    0.272     ** Initial core water saturation.
*so   *con    0.728     ** Initial core oil saturation. (0.660)
*sg   *con    0.000     ** Initial core gas saturation. (0.000)
*temp *con    190.0     ** Initial core temperature, deg F. (190.0)

** INITIAL OIL PHASE MOLE FRACTIONS:
*molefrac *oil *con
               0.000000      ** WATER
               0.000000      ** N2
               0.000000      ** C1
               0.000000      ** CO2
               0.010300      ** C2-C4
               0.038700      ** C5-C6
               0.308900      ** C7-C11
               0.346300      ** C12-C17
               0.295800      ** C18+


**  =============== NUMERICAL CONTROL  ========================
*numerical

**  ALL OF THESE CAN BE DEFAULTED.
*north 8    *newtoncyc 8    *itermax 15
*north 10   *newtoncyc 10   *itermax 15

*unrelax -1

**norm      press 15    satur .1    temp 40   y  0.1   x  0.1
*norm       press 15    satur .1    temp 40   y  0.1   x  0.1

**converge press .15    satur .002  temp .5  y .002  x .002
*converge  press .15    satur .05   temp .5  y .05   x .05

**  MAXIMUM NUMBER OF TIMESTEPS:
*maxsteps 9999

*run

**  =============== RECURRENT DATA  =======================

*time -0.9  dtwell 0.001
```

```
well 1 'INJECTOR'  injector *mobweight 1
operate gas  725.0e+03
incomp gas 0.0 1.0 8*0.0        ** nitrogen injection
tinjov 104                      ** injection temperature F.
perf 1 ** i  j  k  wi(gas)
         1  1  1  3.0e+03


well 2 'PRODUCER'  producer 2
operate bhp 3500.0
geometry k -1 1 1 0  ** Linear pressure drop at tube end
perf geo 2  ** i  j  k
            1  1  22

*tmpset *ijk 1 1 1:22   190.0    ** lose heat above 190 F
*uhtr   *ijk 1 1 1:22    -2.5    ** from zones 3 to 22.


*time -0.7

injector *mobweight 1
operate gas 200.0e+03           ** cm3/hr
incomp gas  0.0 1.0 8*0.0.      ** N2 injection
tinjov 104                      ** injection temperature F.
perf 1 ** i  j  k  wi(gas)
         1  1  1  5.0e+03

*time -0.4

*tmpset *ijk 1 1 1     650.0    ** heat zone 1 to 500 F.
             1 1 2     600.0    ** heat zone 2 to 500 F.
*uhtr   *ijk 1 1 1       1.75
             1 1 2       1.75

*time 0.0                            ** start of air injection.

injector *mobweight 1
operate gas 500.0e+03           ** set air rate at 250 SLH.
incomp gas 0.0 0.79 7*0.0 0.21  ** air injection
tinjov 104.0                    ** air injection temperature F..
perf 1 ** i  j  k  wi(gas)
         1  1  1  5.0e+03

*tmpset *ijk 1 1 1       650.0
             1 1 2       600.0
             1 1 3:22    190.0
*uhtr   *ijk 1 1 1         1.75  ** leave heat on for a while
             1 1 2         1.75
             1 1 3:22      0.0   ** set rest of tube adiabatic.
*time 0.20
*tmpset *ijk 1 1 1     650.0
             1 1 2     600.0     **
*uhtr   *ijk 1 1 1       0.0     ** set zone 1 to adiabatic
             1 1 2       1.75

*time 0.4
*tmpset *ijk 1 1 1     650.0
             1 1 2     600.0
*uhtr   *ijk 1 1 1       0.0     **
             1 1 2       0.0     ** set zone 2 to adiabatic
*time 0.5
*time 0.8
*time 1.2
*time 1.4
*time 1.6
*time 1.9
```

```
*time 2.1
*time 2.4
*time 3.4
*time 3.5
*time 4.0
*time 5.0
*time 5.4 stop
```

PHYSICAL MODELLING OF OIL DISPLACEMENT BY GAS IN WATER-INVADED ZONES

by Bogdan Lepski

ABSTRACT

Injecting gas into water-invaded oil zones can result in the displacement of a substantial fraction of the residual oil. This process is known as the Double Displacement Process (DPP). The physical modelling of this process was investigated at Louisiana State University.[1] Part of the modelling involved conducting experiments using low-pressure transparent cells to gain conceptual insight into double displacement. In addition, experiments were performed using cores of both consolidated and unconsolidated sands. The cores were flooded at a high-pressure to simulate different aspects of the process.

The transparent cell experiments showed that film flow and gravity drainage caused the mobilization of oil and the creation of an oil bank. Oil tended to spread, forming a thin film between the water covering the sand grains and the gas bubble entering the pore spaces. No conventional displacement of oil due to gas injection itself was observed.

Experiments involving laboratory coreflooding proved that gas injection could be used to recover significant quantities of residual oil. The presence of an oil rim prior to gas injection was not necessary for an efficient displacement. In consolidated-sand cores, a significant amount of oil was produced prior to gas breakthrough.

The laboratory experiments also indicated that a significant amount of oil was displaced when gas-flooded zones were subjected anew to waterflooding.

INTRODUCTION

The Double Displacement Process (DDP) involves updip gas injection into a water-invaded oil column in order to mobilize and produce incremental oil.[2] The incremental oil results from the difference in residual oil saturation in the presence of water as compared to that in the presence of gas. Gravity-stable gas displacement causes the formation of an oil bank which builds up progressively as it migrates down the reservoir towards the producing wells. A simplified schematic of a dipping reservoir subjected to DDP is shown in Figure 1.

Gas injection will help to mobilize oil until the oil-water contact returns to its original position. For a favorable set of conditions, the literature suggests that incremental oil recovery on the order of 40% of the initial oil-in-place may be recovered using DDP.[2-11]

Residual oil is left behind invading water because it is trapped by capillary retention forces. Residual oil may be in contact with the surface of the pore network (oil-wet rocks), trapped as globules surrounded by water contacting the pore network surface (water-wet rocks) or a combination of the two may occur when portions of the reservoir are water-wet and others are oil-wet.[12]

EXPERIMENTAL PROCEDURES

The DDP was investigated by two types of experiments: low pressure transparent cells and high pressure cores. A low pressure transparent cell was used to visualise the mechanisms of the process at the pore scale level. To investigate different aspects of the process high pressure corefloods were performed in both consolidated (heterogenious) and unconsolidated (homogenious) cores.

Transparent Cell Experiments

In order to visually observe the mechanisms responsible for oil mobilization and displacement, a transparent cell was built. Figure 2 illustrates the transparent cell construction.

Two glass plates, 24" x 3", were used as the bottom and the top of the cell. Two 1/8" holes were drilled at both ends of the top plate and stainless steel fittings (1/8" in diameter) were glued to the glass to serve as an inlet and outlet for fluid flow. The glass plates were glued together with two pieces of 28 gauge (0.015" in diameter) Ni-Cr wire serving as a spacer. The total volume of the cell was 14 cc with 7 cc of pore volume (50% porosity). To provide the cell with a porous medium, 100-150 mesh cryolite (Na_3AlF_6) granules were placed between the plates. Cryolite was chosen due to its highly water wet properties and because its refractive index is close to that of water thus, cryolite is transparent when it is in contact with water. The grains were consolidated by injecting a mixture of

60% tetraethyl orthosilicate, 32% ethanol, and 8% 0.1 N HCl into the cell. The excess mixture was removed from the cell by flushing the cell with air.[13] The orthosilicate mixture solidified as non-reactive silica and cemented the cryolite grains to create low and high permeability streaks. The transparent cell experimental setup is shown in Figure 3. For injection, a syringe pump was used. After the cell was saturated with water, oil was injected into the top of the cell to displace the water down to its irreducible saturation and the system was allowed to stabilize for one day. The oil used was a mixture of 33% West Hackberry crude with 67% decane. Next, deaerated water was injected into the bottom of the cell to establish a residual oil saturation and the cell was again stabilized for one day. Gas was injected into the top of the cell to simulate the DDP. Due to the slow rate of the process, the experiment was video taped. Selected segments were later spliced together and a short movie summarizing the flood was made. This tape is on file. The VCR camera was fitted with additional optical equipment such as a teleconverter, bellows unit, close-up lenses and a polarizing filter. This arrangement reduced unwanted light reflections and permitted variable scales of magnification from macroscopic 1:1, whole cell size, down to single pore level size 450:1. The oil coalescence due to capillary forces interaction was observed in the uppermost gasflooded section of the cell. The oil bank formation and movement at macroscopic scale was also observed.

High Pressure Corefloods

Two kinds of high pressure cores were used to investigate some of the aspects of the DDP; a homogeneous unconsolidated sand pack and a consolidated, mildly heterogeneous Berea sandstone core. Experimental conditions were selected as close as possible to West Hackberry reservoir conditions. However certain constraints were imposed by the equipment design and capabilities. The pressure and temperature selected for all corefloods were 2000 psi and 160°F. The oil viscosity at 160°F was 3.31 cp (11.78 cp at 74°F).

Berea Corefloods: The Berea sandstone core was about six feet in length and two inches in diameter. Each core was coated with epoxy resin and fiberglass tape and placed in a stainless steel coreholder. Stainless-steel coils were wrapped around the core and used to circulate heated ethylene glycol/water to create a uniform temperature distribution. The coreholder was insulated to minimize heat losses. The annulus of the coreholder was filled with hydraulic oil and pressurized to 1000-1500 psi higher than the highest expected pressure in the core during the experiment. The goal was to keep the core intact under permanent compression. The core assembly was mounted vertically.

An initial permeability check was performed before each experiment by pumping water at constant flow rate and constant pressure drop across the core. Permeability was measured in both flow directions. The permeability of the Berea core was 380 md. These measurements were performed at 160 °F and 2000 psig.

The producing end of the core was connected to a panel with a sight glass for visual observations at high pressure and a back pressure valve was used to maintain a constant pressure at the producing end. Produced fluids were separated and measured in an atmospheric pressure separator connected to a gas meter. Pressures at both ends and the pressure drop across the core were measured using transducers and Bourdon tube gauges. A schematic illustration of the consolidated core experimental setup is shown in Figure 4.

After the core was saturated with water, West Hackberry stock-tank oil was injected into the top of the core until an irreducible water saturation had been established. After one day of stabilization time, water was injected to establish a residual oil saturation in the presence of water. Water was injected until the water-cut reached 95%. After the oil injection and the water injection, effective permeabilities to oil and water were measured at the residual saturations.

After the residual oil saturation had been established in the core, gas was injected until the produced stream reached a 95% gas cut, as observed through the sight glass at reservoir conditions. The core was then shut-in for a period of time to allow oil migration. After the shut-in period, gas was injected to maintain core pressure while oil was being produced. Production continued until gas cut again reached 95%. After every few days of shut-in, the producing end of the core would be opened again and additional oil would be produced. This sequence of shut-in followed by oil production was repeated several times. Oil continued to be produced, but at diminishing quantities. Eventually the experiment was terminated because of time constraints. The first experiment lasted 58 days and the second experiment lasted 24 days.

Two experiments were conducted; one in which an oil rim had been injected into the top of the core prior to the gas injection and one in which no oil rim had been injected. The purpose of this was to see if whether or not a reservoir containes an oil rim is an important factor in the DDP.

Unconsolidated Coreflood: In order to investigate DDP in a homogenious rock enviroment, an unconsolidated core apparatus with a much higher permeability and cross-sectional area was built. The apparatus consisted of a 9.5 ft long, 0.2225 ft diameter steel cylinder, packed with 80-120 mesh Ottawa sand. Sand and water were added together and the holder was vibrated to ensure a tight pack. The core assembly was mounted vertically and a brass tube heating coil was wrapped around the coreholder. The system was insulated to minimize heat losses. The average core porosity was 42%. The permeability was 2830 md. All procedures in the unconsolidated core experiment were the same as in the Berea experiments. An oil rim was injected into the top of the core prior to gas injection. The gas injection rate was sufficiently low to avoid gas fingering.

EXPERIMENTAL RESULTS

Transparent Cell

The transparent cell experiments allowed visual observation of the microscopic gas-oil-water displacements, oil film flow development and oil bank growth. Two transparent cell experiments were performed. It was observed that when a gas bubble entered the pore, oil spread over the water covering the sand grains and tended to flow as a thin film as depicted in Figure 5. Oil film flow created an oil bank which grew with time in the lower portion of the gas swept zone. This process is illustrated in Figure 6. Oil mobilization only occured after excessive water was displaced and conditions for free film flow were created. There was no oil mobilization observed due to gas displacement itself. The oil film flow rate was much slower than the gas injection (displacement) rate. Significant amounts of gas were trapped below the oil bank, never migrated updip and were produced prior to oil bank arrival. This is illustrated in Figure 7. An edited video of these processes is currently being made and will be available to interested readers.

Laboratory Corefloods

Unconsolidated core experiment yielded significant oil production, but only after the initial gas displacement and subsequent shut-in period. Most of the displaceable water was produced prior to arrival of the oil bank. The water was followed by rapid gas breakthrough. The irreducible water saturation, as measured after the oil flood, remained the same after gas injection was completed.

Periodically the producing end of the core would be opened to production and the oil and gas produced until the gas - cut exceeded 95 % of produced fluids, as observed at core pressure through the sight glass. The end of the oil bank was indicated by a sharp increase in the gas cut. This production-shut-in cycle was repeated several times.

The plot of oil saturation (excluding the volume of oil in the initial oil rim) vs. time, including production before and after gas breakthrough, for the experiment is shown in Figure 8.

Some gas was produced in the beginning of each oil production cycle. This may indicate that some gas was trapped in the bottom portion of the core. Similar gas entrapment was also observed in the transparent cell experiment.

The log-log plot of $1-N_p$ (N_p = fraction of movable oil) vs. dimensionless time after gas breakthrough as described by Hagoort[5], as depicted in Figure 9, gives a straight line. Extrapolating from that plot, future oil production down to the final residual oil saturation in the presence of gas can be predicted.

In the Berea core experiments, unlike the unconsolidated core experiment, significant oil production was observed prior to gas breakthrough. The increase in early oil production may be attributed to penetration of zones bypassed by water and preferentially oil-wet portions of the core. Only a portion of the movable water was displaced before gas breakthrough. Additional water production was observed during each gas injection cycle.

The amount of incremental oil produced prior to gas breakthrough for a core that contained no initial oil rim was almost equal to that produced for a core that did contain an initial oil rim. Thus there was no significant improvement in the DDP efficiency due to the presence of an initial oil rim. This indicates that a reservoir does not have to have an oil rim in order to be a candidate for the DDP. A comparison of oil production before gas breakthrough with and without an oil rim is shown in Figure 10.

After each coreflood, it was observed that significant amounts of oil were produced during the initial stage of core cleaning. During cleaning, water was injected at the bottom of the core at a slow rate. Gas was initially produced followed by a significant amount of oil production. For the last Berea sandstone experiment approximately 7.5% pore volume of oil was produced. In all preceding experiments, significant quantities of oil were produced, but the quantity was not measured. A plot of saturation vs. time for the second Berea sandstone experiment is shown in Figure 11. The abrupt drop in oil saturation from about 26% to 17% was due to the water injection. It may be worthwhile to run additional experiments to establishing the mechanisms responsible for this phenomena. There may be some practical benefit from this observation. Single well reservoirs with a water-drive may be potential candidates for DDP - secondary waterflooding process, since both gas injection and oil bank production could be performed using the same well. Another possible benefit is that at the conclusion of the DDP, the updip wells could be used to blow down the injected gas while allowing the water to once again invade and displace additional oil.

CONCLUSIONS

The research presented here combined high pressure, high temperature corefloods with low pressure, room temperature transparent cell floods to investigate the Double Displacement Process. On the basis of experimental results and observations the following conclusions can be drawn:

1. Laboratory corefloods proved that the Double Displacement Process was capable of recovering significant quantities of residual oil from water-invaded regions.
2. There was no influence of the presence of an initial oil rim on DDP efficiency.
3. In core studies oil production after gas breakthrough can be extrapolated based on a few oil production data points which can be collected in a reasonable time.
4. Significant amounts of oil were produced when gasflooded zones were subjected to a second invasion of water.
5. There was no significant oil mobilization or oil bank formation prior to gas breakthrough.
6. The oil bank formation after gas breakthrough resulted from oil film flow and gravity drainage.
7. Significant amounts of gas were trapped below the oil bank and some gas was produced along with oil.

ACKNOWLEDGMENTS

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FIGURES
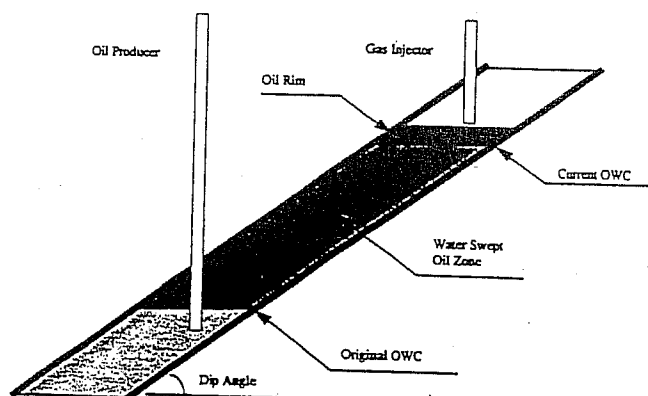
Figure. 1. Schematic of the Double Displacement Process
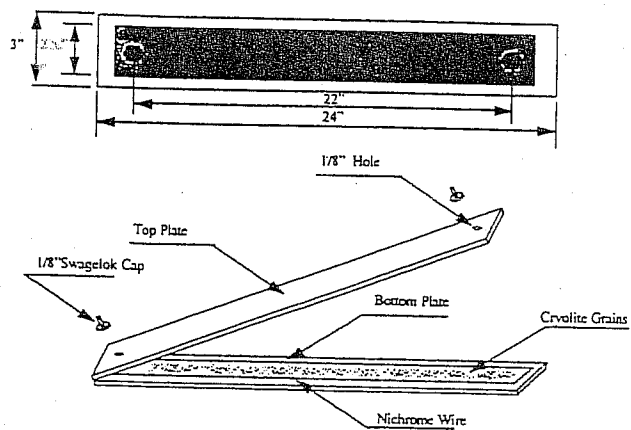
Figure 2. Schematic of the Transparent Cell
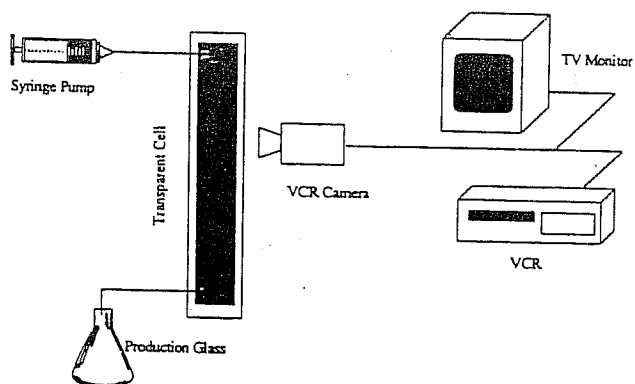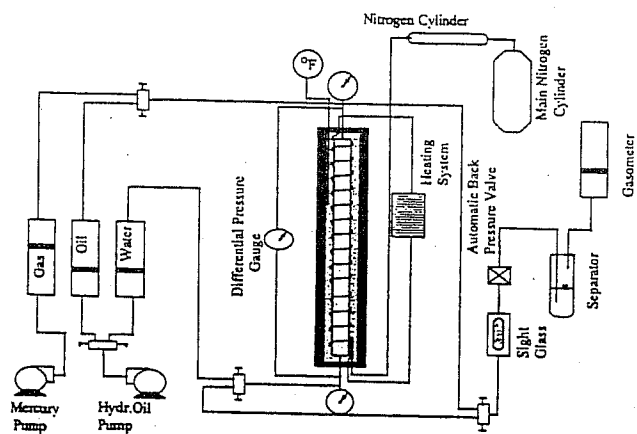

Figure 3. Transparent Cell Experimental Setup

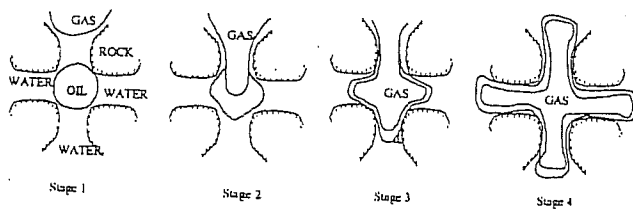Figure 4. Consolidated Core Apparatus

D-6

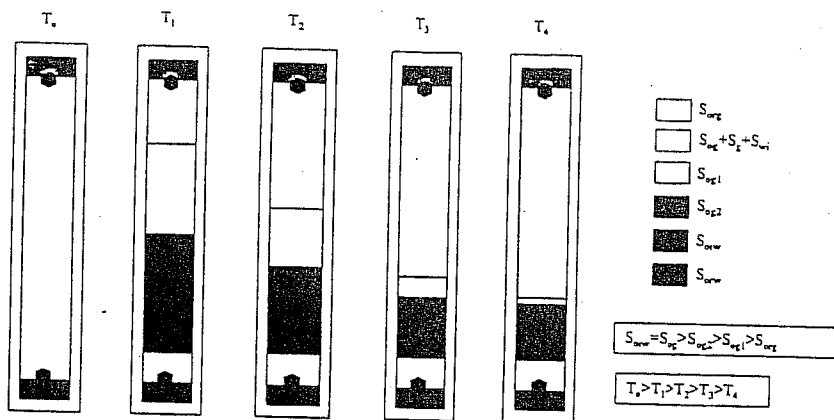Figure 5. Gas Bubble Invasion
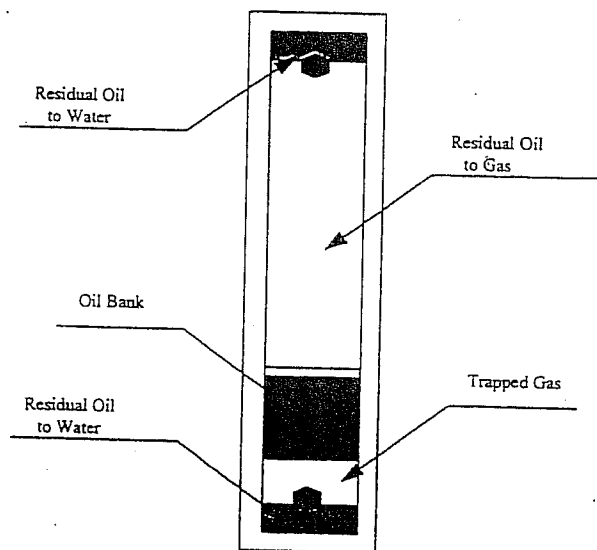

Figure 6. Oil Film Growth in transparent Cell

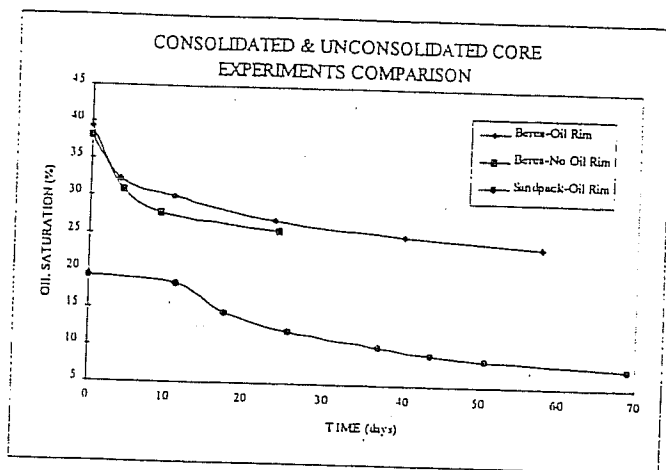Figure 7. Gas Trapping in the Bottom of Transparent Cell

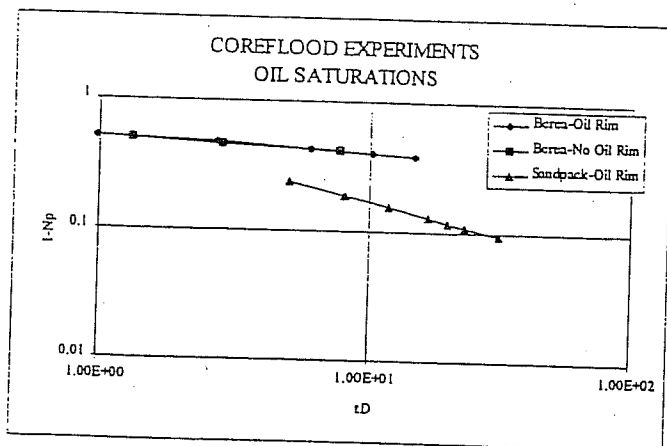Figure 8. Coreflood Experiments Oil Saturation vs. Time

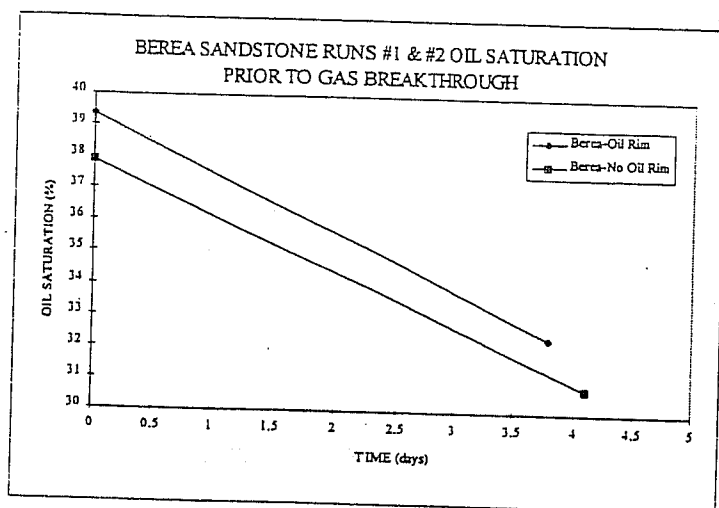Figure 9. Coreflood Experiments Log-Log Plots

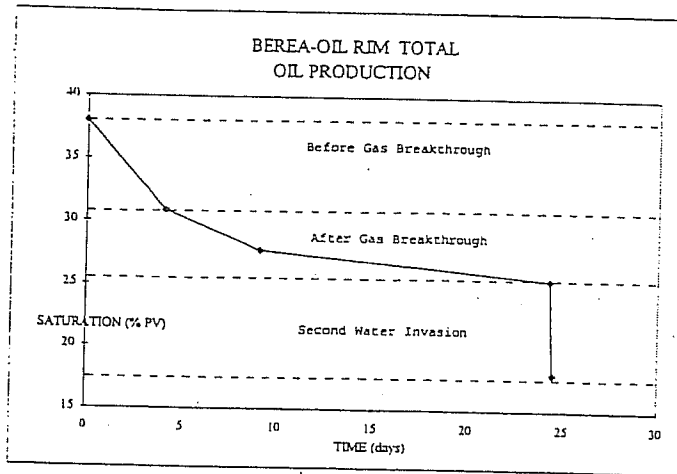Figure 10. Coreflood Experiments Log-Log Plots

BEREA-OIL RIM TOTAL
OIL PRODUCTION

Figure 11. Total Oil Production for Berea-Oil Bank